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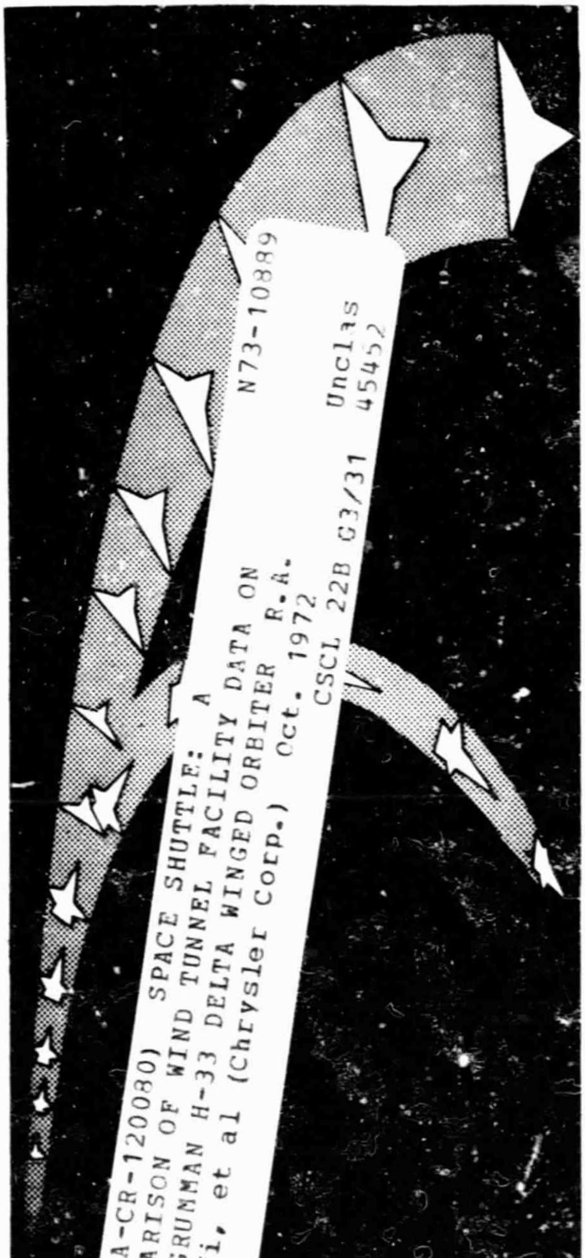
DMS-SPR-0009
CR-120,080
OCTOBER, 1972



—SPACE SHUTTLE—

A COMPARISON OF WIND TUNNEL FACILITY DATA ON THE GRUMMAN H-33 DELTA WINGED ORBITER

by

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NASA

MARSHALL SPACEFLIGHT CENTER

This document should be referenced as NASA CR-120,080

DMS-SPR-0009
CR-120,080
October, 1972

SADSAC/SPACE SHUTTLE

WIND TUNNEL TEST DATA REPORT

CONFIGURATION:	Grumman H-33 Space Shuttle Orbiter
PURPOSE:	Comparison of Aerodynamic Data Obtained From Four Different Wind Tunnel Facilities on the Grumman H-33 Delta-Winged Orbiter Configuration
FACILITIES:	MSFC 14 x 14 ft Trisonic Wind Tunnel
	LaRC 8 ft Transonic Pressure Tunnel
	LaRC 4 x 4 ft Unitary Plan Wind Tunnel
	LaRC 3 x 7 ft Low Turbulence Pressure Tunnel
REPORT AGENCY:	Northrop Services, Inc.
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Contract NAS 8-4016 Amendment 174 DRL 297 - 84a

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SUMMARY

Presented in this report is a comparison of longitudinal and lateral-directional stability and control characteristics of the Phase B Grumman H-33 orbiter configuration obtained from 6 tests conducted in 4 different Government facilities. The H-33 orbiter configuration does not include drop tanks. Slope data are used as the medium for comparison. The slope data were computed using the SADSAC system and have been reduced to a common reference system. Slopes are presented in the stability-axis system with the exception of C_{N_α} which is, by definition, in the body-axis system.

Data used for comparison were selected based on common configurations wherever possible. Where direct configuration comparisons were not possible, the parameters selected for comparison are regarded as insensitive to the noted differences. Factors considered in comparing the various data were scaling effects, balance operating ranges, balance sensitivities and control deflection accuracies. All factors considered, the comparison among data obtained from the various facilities is excellent. The minor differences in stability and control characteristics are well within the accuracy band of preliminary design model construction specifications.

Tests and test data for the comparison were:

- MSFC 504 - 30 August through 1 September 1971
- MSFC 507 - 13-18 October 1971 and 13-19 January 1972
- LaRC 8-TPT 604 - 29 September through 5 October 1971
- LaRC UPWT 964 - 20 September through 24 September 1971
- LaRC UPWT 969 - 15 November through 2 December 1971
- LaRC LTPT 75 - 13 September through 17 September 1971

NOMENCLATURE

(General)

SYMBOL	SADSAC SYMBOL	DEFINITION
α	ALPHA	Angle of attack, angle between the projection of the wind X_W-axis on the body X-Z plane and body X-axis, degrees
β	BETA	Sideslip angle, angle between the wind X_W axis and the projection of this on the body X-Z plane, degrees
M	MACH	Mach number, speed of vehicle relative to surrounding atmosphere divided by local speed of sound
q	Q(PSI) Q(PSF)	dynamic pressure, $\rho V^2/2$ psi psf
ρ		Air density, kg/m^3, $slugs/ft^3$
V		Speed of vehicle relative to surrounding atmosphere, m/sec, ft/sec
RN/L	RN/L	Reynolds number per unit length, million/ft
F		Force, F, lbs
M		Moment, M, in-lbs
δr_L	LRUDDR	Left split rudder surface deflection angle, degrees, positive deflection, trailing edge to the left
δr_R	RRUDDR	Right split rudder surface deflection angle, degrees, positive defection, trailing edge to the left
δ_r	RUDDER	Asymmetrical split rudder deflection for directional control $(\delta r_L + \delta r_R)/2$, degrees
δe_L	ELVN-L	Left elevon, surface deflection angle, positive deflection, trailing edge down, degrees
δe_R	ELVN-R	Right elevon, surface deflection angle, positive deflection, trailing edge down, degrees
δ_a	AILERN	Total aileron deflection angle in degrees, $(\delta e_L - \delta e_R)/2$
δ_e	ELEVTR	Total elevator deflection angle in degrees, $(\delta e_L + \delta e_R)/2$

NOMENCLATURE

(Reference and C.G. Definition)

SYMBOL	SADSAC SYMBOL	DEFINITION
S_{ref}	SREF	Reference area, m^2, ft^2
ℓ_{ref}	LREF	Reference length, m, ft, in.
b_{ref}	BREF	Wing span for reference span, m, ft, in.
c.g.		Center of gravity
MRP	MRP	Abbreviation for moment reference point
	XMRP	Abbreviation for moment reference point on X-axis
	YMRP	Abbreviation for moment reference point on Y-axis
	ZMRP	Abbreviation for moment reference point on Z-axis

NOMENCLATURE

(Body and Stability Axis System)

SYMBOL	SADSAC SYMBOL	DEFINITION
		(Common to Both Axis Systems)
C_m	CLM	Pitching moment coefficient, $M_Y/qS\ell ref$
C_Y	CY	Side force coefficient, F_Y/qS
		Stability Axis System
C_L	CL	Lift force coefficient F_L/qS
C_D	CD	Drag force coefficient, F_D/qS
C_n	CLN	Yawing moment coefficient, $M_{Z,s}/qSb_{ref}$
C_ℓ	CSL	Rolling moment coefficient, $M_{X,s}/qSb_{ref}$
		Derivatives
C_{m_α}	D(CLM)	Derivative of pitching moment coefficient with respect to alpha (alpha = 0 to 5°), per degree
C_{n_β}	DCLNDB	Derivative of yawing moment coefficient with respect to beta (beta = ± 5°) per degree, stability axis system.
C_{ℓ_β}	DCSLDB	Derivative of rolling moment coefficient with respect to beta (beta = ± 5°) per degree, stability axis system.
C_{Y_β}	CYBETA	Derivative of side force coefficient with respect to beta (beta = ± 5°) per degree, stability axis system
$C_{n_{\delta_r}}$	DCLNDR	Incremental yawing moment due to rudder deflection. Algebraic sum of the yawing moment coefficients of two runs divided by the algebraic sum of the rudder deflection, stability axis system, per degree
$C_{\ell_{\delta_r}}$	DCSLDR	Incremental rolling moment due to rudder deflection. Algebraic sum of the yawing moment coefficients of two runs divided by the algebraic sum of rudder deflection, stability axis system, per degree.

$C_{Y_{\delta_r}}$	DCY/DR	Incremental side force due to rudder deflection. Algebraic sum of the side force coefficients of two runs divided by the algebraic sum of the rudder deflection, stability axis system, per degree.
$C_{n_{\delta_a}}$	DCLNDA	Incremental yawing moment due to aileron deflection. Algebraic sum of the yawing moment coefficients of two runs divided by the algebraic sum of the aileron deflection, stability axis system, per degree.
$C_{\ell_{\delta_a}}$	DCSLDA	Incremental rolling moment due to aileron deflection. Algebraic sum of the rolling moment coefficients of two runs divided by the algebraic sum of the aileron deflection, stability axis system, per degree.
$C_{Y_{\delta_a}}$	DCY/DA	Side force due to aileron deflection. Algebraic sum of the side force ceofficients of two runs divided by the algebraic sum of the aileron deflection angle of the runs, per degree.
$C_{L_{\delta_e}}$	DCL/DE	Incremental lift force due to elevon deflection. Algebraic sum of the lift force coefficients of two runs divided by the algebraic sum of the elevon deflection angle of the runs, stability axis system, per degree.
$C_{m_{\delta_e}}$	DCLMDE	Incremental pitching moment due to elevon deflection. Algebraic sum of the pitching moment coefficients of two runs divided by the algebraic sum of the elevon deflection angle of the runs, stability axis system, per degree.
C_{N_α}	D(CN)	Derivative of normal force coefficient with respect to alpha (alpha = 0 to 5°), per degree.

INTRODUCTION

The Phase-B Space Shuttle Study has offered a unique opportunity for aerodynamicists involved in configuration development. Similar models of various scale sizes were tested in different wind tunnels and the data stored for retrieval and analysis in a common data management system. These circumstances allowed engineers to consider the relative merits of various testing techniques in configuration development. In particular, Marshall Space Flight Center has evaluated the feasibility of testing relatively small scaled models of various Space Shuttle orbiter and booster configurations in the MSFC 14-inch TWT over large angle of attack ranges. This report compares data obtained on the Grumman H-33 orbiter in the 14-inch TWT with those obtained at other facilities. The H-33 orbiter was selected because a sufficient data base existed from other tunnels for comparison over the angle of attack and Mach number range of the MSFC facility. The results derived from this study demonstrate the feasibility of using various model sizes and wind tunnel facilities to accomplish configuration development in an economical fashion. The results compare favorably with closely controlled studies of transport aircraft utilizing identical models in various wind tunnels (Ref. 2). In order to gain an appreciation for the data comparison accuracies, the configurations are presented, data reduction details presented, balance operating ranges and nominal loads presented and Reynolds number comparisons are made.

CONFIGURATION INVESTIGATED

The six tests used in this comparison utilized identical model components within the accuracy of model construction techniques. The model components comprising the basic H-33 orbiter configuration were as follows:

B_5 - Basic H-33 orbiter body

W_4 - Basic H-33 orbiter wing

V_5 - Basic H-33 orbiter vertical tail

These components are described in the Model Component description Sheets in the Appendix.

The four LaRC tests used transition grit for fixed transition while the MSFC tests did not include grit. Previous experience in the MSFC TWT has indicated that transition strips do not materially affect the basic stability and control slope data.(Refs. 1 and 4).

In order to obtain a broader range of comparison, it was necessary to use data from LaRC UPWT 969 test with the rudder flared at 30° to compare with MSFC data obtained with zero degree rudder flare. Only longitudinal stability characteristics are compared and the rudder flare effects assumed tobe negligible. The rudder flare differences are noted on the comparison plots.

DATA REDUCTION

The data from the six tests were reduced along and about a system of stability axes passing through a nominal center of gravity located at F.S. 1274.4, W.L. 391.4 and B.L.0 (full-scale coordinates). The full scale constants used to reduce the data to coefficient form were as follows:

$$S_{ref} = 4840 \text{ sq. ft.}$$
$$\ell_{ref} = 1620 \text{ in.}$$
$$b_{ref} = 1134 \text{ in.}$$

The following table gives the six tests, the balances used and the above constants in model scale.

TEST	BALANCE	MODEL SCALE	S_{ref} (in.^{2})	ℓ_{ref} (in.)	b_{ref} (in.)	c.g. loc. (in. from nose)
MSFC 504	MSFC 201	.003366	7.8965	5.453	3.817	3.6162
MSFC 507	MSFC 201	.003366	↓	↓	↓	↓
LaRC UPWT 964	LaRC UT 34	.0148148	152.9676	24.0	16.8	15.917
LaRC UPWT 969	LaRC UT 34	.0148148				
LaRC 8-TPT 604	LaRC 739	.0148148				
LaRC LTPT 75	LaRC 832C	.0148148	↓	↓	↓	↓

BALANCE INFORMATION

Representative maximum model loads and balance capacities for each test are presented in Table 1. As the data presented in Table 1 indicates, the maximum measured loads and moments for some tests represent a small percentage of balance capacity. The bulk of data used in these comparisons were obtained at less than maximum balance capability and could explain the minor differences encountered in some parameters.

Table I. BALANCE INFORMATION

TEST	BALANCE	REPRESENTATIVE LOADS AT COMPARISON CONDITIONS/BALANCE CAPACITY					
		NF (lbs)	SF (lbs)	AF (lbs)	PM (in. lbs)	YM (in. lbs)	RM (in. lbs)
MSFC 504	MSFC #201	45/60	15/20	6.6/30	40/120	4/40	4/25
MSFC 507	MSFC #201	45/60	15/20	6.6/30	40/120	4/40	4/25
LaRC 8-TPT 604	LaRC 739	750/1200	18/500	85/125	1350/2000	80/2000	555/1000
LaRC UPWT 964	LaRC UT 34	340/600	55/300	50/50	520/1000	50/600	95/300
LaRC UPWT 969	LaRC UT 34	300/600	30/300	50/50	145/1000	80/600	100/300
LaRC LTPT 75	LaRC 832C	250/1000	35/250	20/85	250/2000	65/1000	125/500

DATA COMPARISON DISCUSSION

The longitudinal and lateral directional stability and control characteristics are compared among the various facilities. Generally, a sufficient data base existed on the H-33 to allow a good comparison of longitudinal directional stability and longitudinal and lateral control. The lateral directional stability comparison was limited due to lack of data from facilities other than the MSFC 14-inch tunnel.

In general, the data compared very well among the various facilities. Excellent agreement was found for basic pitch and directional stability among the facilities compared. Control effectiveness differences exist but are well within test objectives. The differences in control effectiveness can be accounted for by considering the sensitivity to control positioning and Reynolds number effects. Tunnel blockage due to model cross-section and wake and tunnel wall interference are considered to be negligible at the angles of attack selected for comparison. The longitudinal and lateral directional characteristics comparisons are discussed in the following sections. It should be noted that the curves are faired through the MSFC data to provide a basis for comparison realizing the user would use all data points to establish a design curve. A summary of the comparisons made is given in Table II.

SCALED REYNOLDS NUMBER COMPARISONS

Presented in Figure 2 are the scaled Reynolds numbers based on model length. Large differences in scaled Reynolds number exist between MSFC 504, MSFC 507 and LaRC 8-TPT-604 at subsonic Mach numbers and MSFC 504, MSFC 507, and LaRC UPWT 969 at supersonic Mach numbers. Previous Phase B Reynolds number studies at Ames and Langley have shown the importance of matching Reynolds number (Refs. 3 & 6). Although the major effect of Reynolds number occurs in drag, stability can be affected when separated flow occurs.

H-33 DISCUSSION

LONGITUDINAL-DIRECTIONAL STABILITY

The plots of C_{N_α} and C_{m_α} vs. Mach number are presented in Figure 3.

Excellent agreement was found at all Mach numbers for C_{m_α} data from the four facilities compared. It is also seen that the presence of $\pm$ 30° rudder flare during LaRC UPWT 969 has no apparent effect on longitudinal stability.

C_{N_α} shows excellent agreement at all supersonic Mach numbers but with some scatter in the subsonic/low transonic ranges. This is readily explained by the fact that in this region, the slope of the C_{N_α}-Mach number curve (dC_{N_α}/dM) is rapidly changing and therefore minute changes in M yield large differences in C_{N_α}.

H-33 DISCUSSION

LATERAL-DIRECTIONAL STABILITY

The plots of the lateral directional stability derivatives as a function of Mach number for zero angle of attack are presented in Figure 4, and for 10° angle of attack in Figure 5.

A limited amount of data was available for comparing the lateral-directional stability. Generally the comparison is quite good between MSFC and LaRC where data exist.

H-33 DISCUSSION

The rudder power derivatives as a function of Mach number for angles of attack of 0, 10, and 20 degrees are presented in Figure 6.

There were only two sets of data available for comparison of rudder deflection derivatives. These were from LaRC UPWT 969 and MSFC 507. On the whole the comparison was good with a maximum discrepancy of around .0006 appearing in $C_{Y_{\delta_r}}$ between the two tests. This maximum difference occurred around Mach 3.0 while all data beyond Mach 3.6 compared much closer. The trends of the three derivatives compared appear to be consistent over the alpha range of 0 to 20° with just a slight relative shift in the values of the derivatives. This seems to indicate that the discrepancies are a function of some constant quantity rather than a variable such as alpha, Mach number or Reynolds number. A possible source of error is the angle of the deflection surface itself. The rudder derivatives compared were based on deflection angles of 0° and $\pm$ 5° for a net $d\delta_r$ of 5°. Slight errors in the deflection angles can yield much larger errors in the value of the derivatives, particularly in a case such as this where the $d\delta$ is relatively small.

H-33 DISCUSSION

The aileron derivatives as a function of Mach number for angles of attack of 0, 10 and 20 degrees are presented in Figure 7.

As in the case of the rudder derivatives, only two sets of data were available for comparison. And again, the same two tests were involved. All three derivatives showed very close agreement over the Mach and alpha range compared. Again, a possible cause of discrepancies that exist in the aileron derivatives is the deflection angle. The derivatives compared were based on a $d\delta_a$ of 10° which implies a 10 per cent error in the derivative for a 1° error in deflection angle and an additional indeterminate error in the values of the coefficients obtained at deflection angles other than those assumed. Because of the complications involved in the construction and installation of these angled surfaces, it is unrealistic to assume that some error does not exist or is negligible.

H-33 DISCUSSION

The elevator power derivatives as a function of Mach number for angles of attack of 0, 10, and 20 degrees are presented in Figure 8.

The comparison of elevon deflection derivatives was done in two parts. The first of this was over the subsonic and transonic regions comparing Marshall Test 507 and LaRC 8-TPT 604 where data were obtained on the H-33 with zero degree rudder flare. The second part was the supersonic region comparing more data from MSFC 507 with that from LaRC UPWT 969 but now with $\pm$ 30° rudder flare. Connecting these two comparisons is some additional data obtained in the Mach 2.0 region from LaRC UPWT 964, also with $\pm$ 30° rudder flare. This has been included simply to show this connection and the general shape of the entire curve.

Supersonically the comparison is excellent for all three angles of attack investigated. The elevon derivatives were computed based on a $d\delta_e$ of −20° which implies that slight deflection angle errors do not affect the elevon derivatives as much as they did in the calculation of the rudder and aileron derivatives.

Subsonically, there is some scatter in the values of the derivatives between the two tests. At zero angle of attack the trends at least appear to be similar while at the other end of the scale at α = 20°, the differences are larger for $C_{L_{\delta_e}}$. There appears to be several possible causes for this data scatter. The first is that in the case of the Langley test, fixed transition with grit strips was employed while Marshall did not use fixed transition. This allowed the boundary layer to seek natural transition which undoubtedly varied with angle of attack as opposed to the constant location of transition caused by the grit on the Langley model.

A second possible source of discrepancy in the subsonic region is the fact that the Langley test was conducted at characteristic Reynolds numbers (based on body length) between two and three times larger than those at Marshall. This is shown in Figure 1 for all the tests compared.

This difference in Reynolds number may have additional effect on the boundary layer transition problem mentioned earlier and can thus lead to further resultant differences in control effectiveness data.

Another possible source of discrepancy that bears mentioning is balance sensitivities. Table I gives maximum representative loads for the conditions considered in this comparison over the balance capacity for each force and moment. It is seen that in many cases data has been compared directly after being taken from completely different balances operating at opposite ends of their design capacities.

Table II. SUMMARY DATA PLOT INDEX

TITLE	PLOTTED COEFFICIENTS SCHEDULE	CONDITIONS VARYING	PLOT PAGES
Longitudinal Stability	A	Mach	22
Lateral Directional Stability - $\alpha = 0°$	B	Mach	24
Lateral Directional Stability - $\alpha = 10°$	B	Mach	26
Rudder Power Derivatives - $\alpha = 0°$	E	Mach	28
Rudder Power Derivatives - $\alpha = 10°$	E	Mach	29
Rudder Power Derivatives - $\alpha = 20°$	E	Mach	30
Aileron Power Derivatives - $\alpha = 0°$	C	Mach	31
Aileron Power Derivatives - $\alpha = 10°$	C	Mach	32
Aileron Power Derivatives - $\alpha = 20°$	C	Mach	33
Elevon Power Derivatives - $\alpha = 0°$	D	Mach	34
Elevon Power Derivatives - $\alpha = 10°$	D	Mach	35
Elevon Power Derivatives - $\alpha = 20°$	D	Mach	36

PLOTTED COEFFICIENTS SCHEDULE

(A) D(CLM), D(CN) Vs. Mach

(B) DCLNDB, DCSLDB, CYBETA Vs. Mach

(C) DCLNDA, DCSLDA, DCY/DA Vs. Mach

(D) DCLMDE, DCL/DE Vs. Mach

(E) DCLNDR, DCSLDR, DCY/DR Vs. Mach

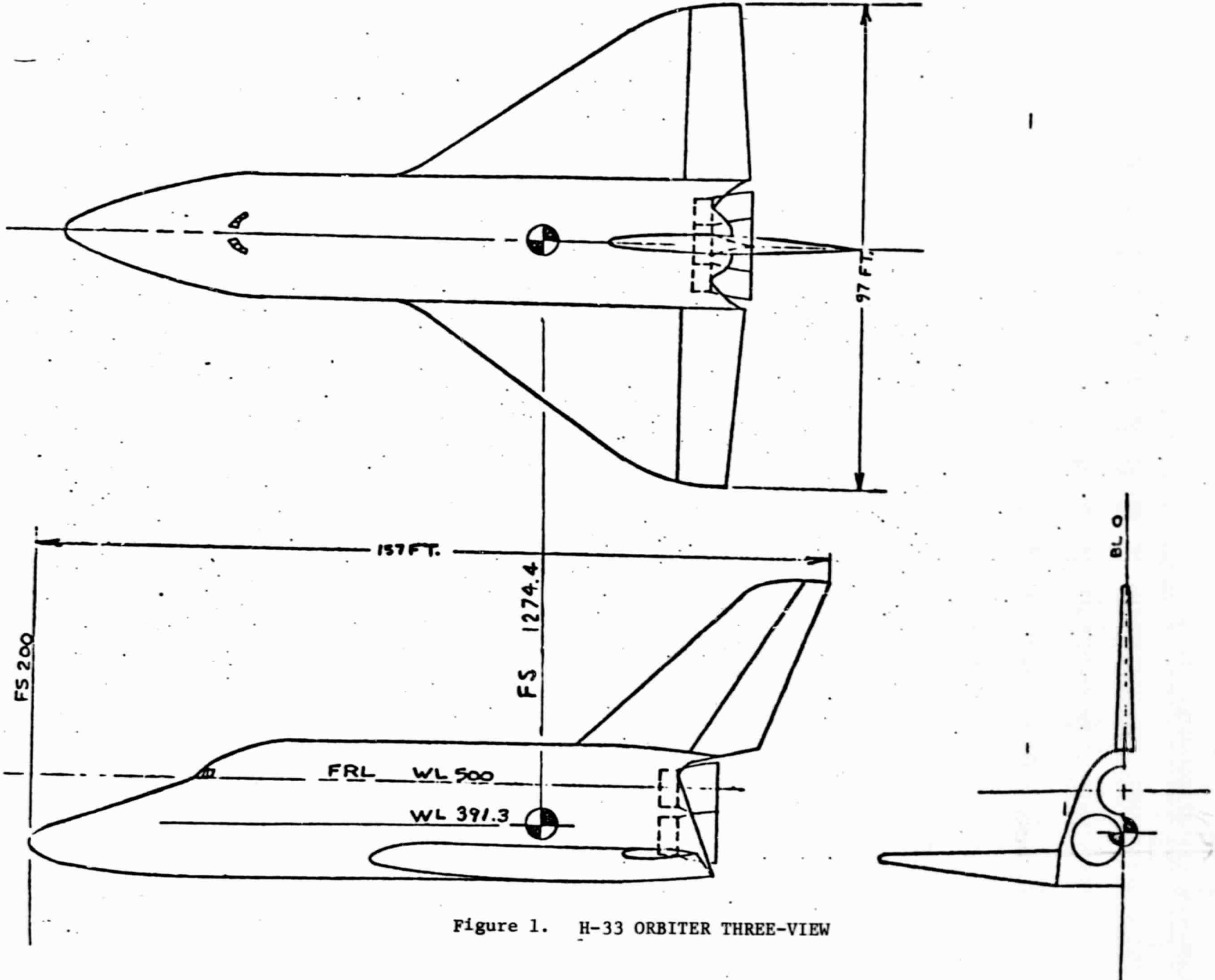


Figure 1. H-33 ORBITER THREE-VIEW

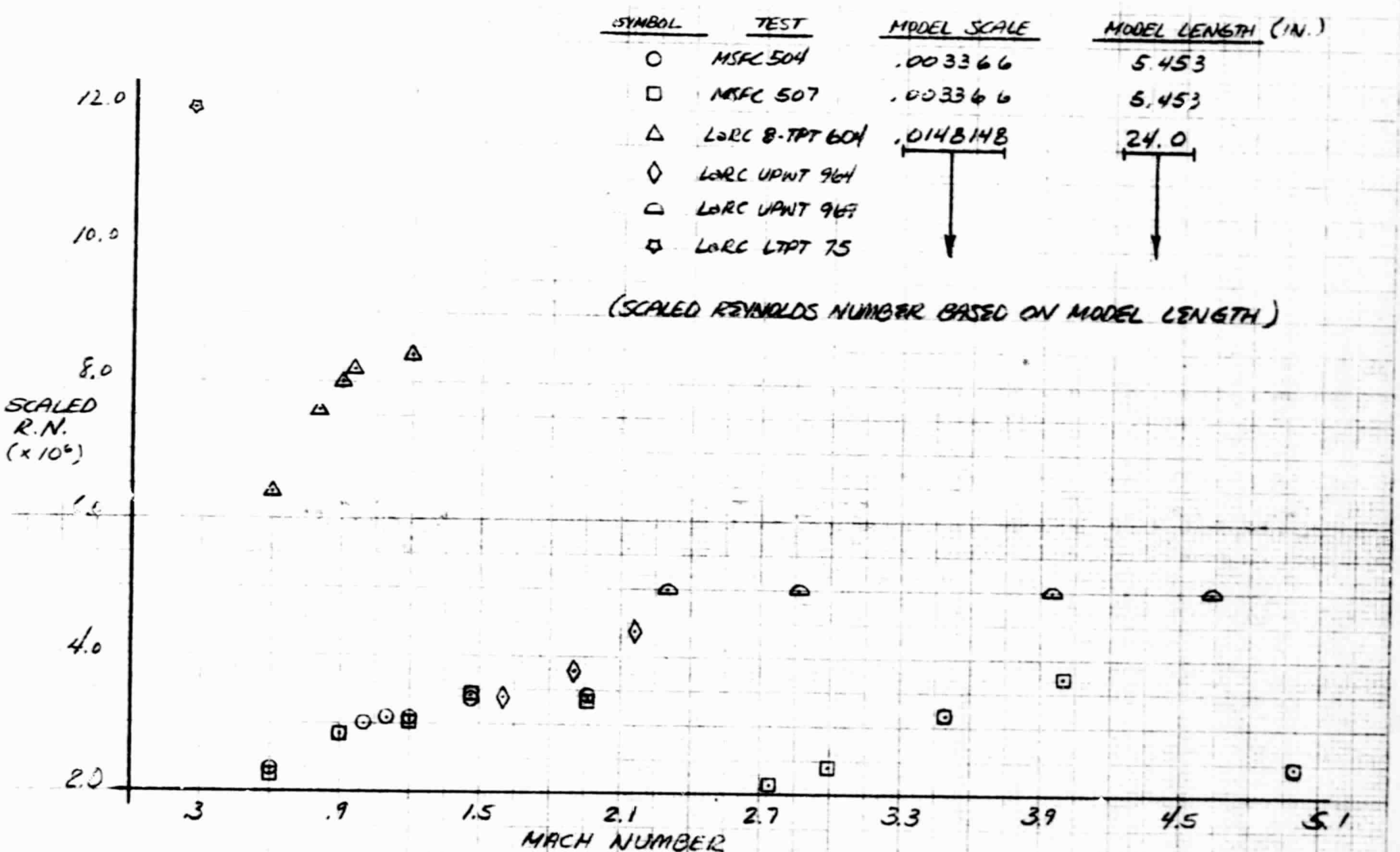
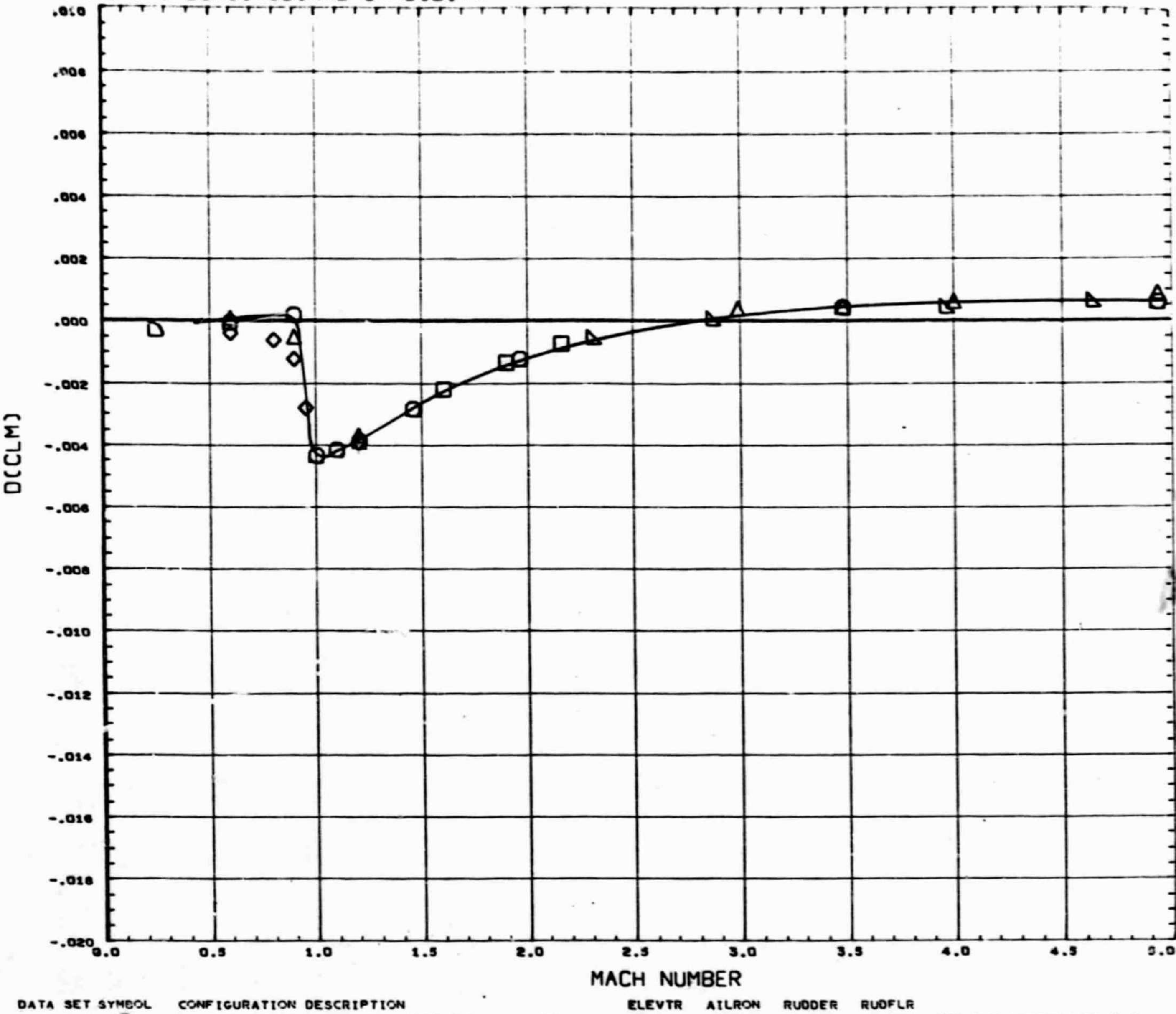


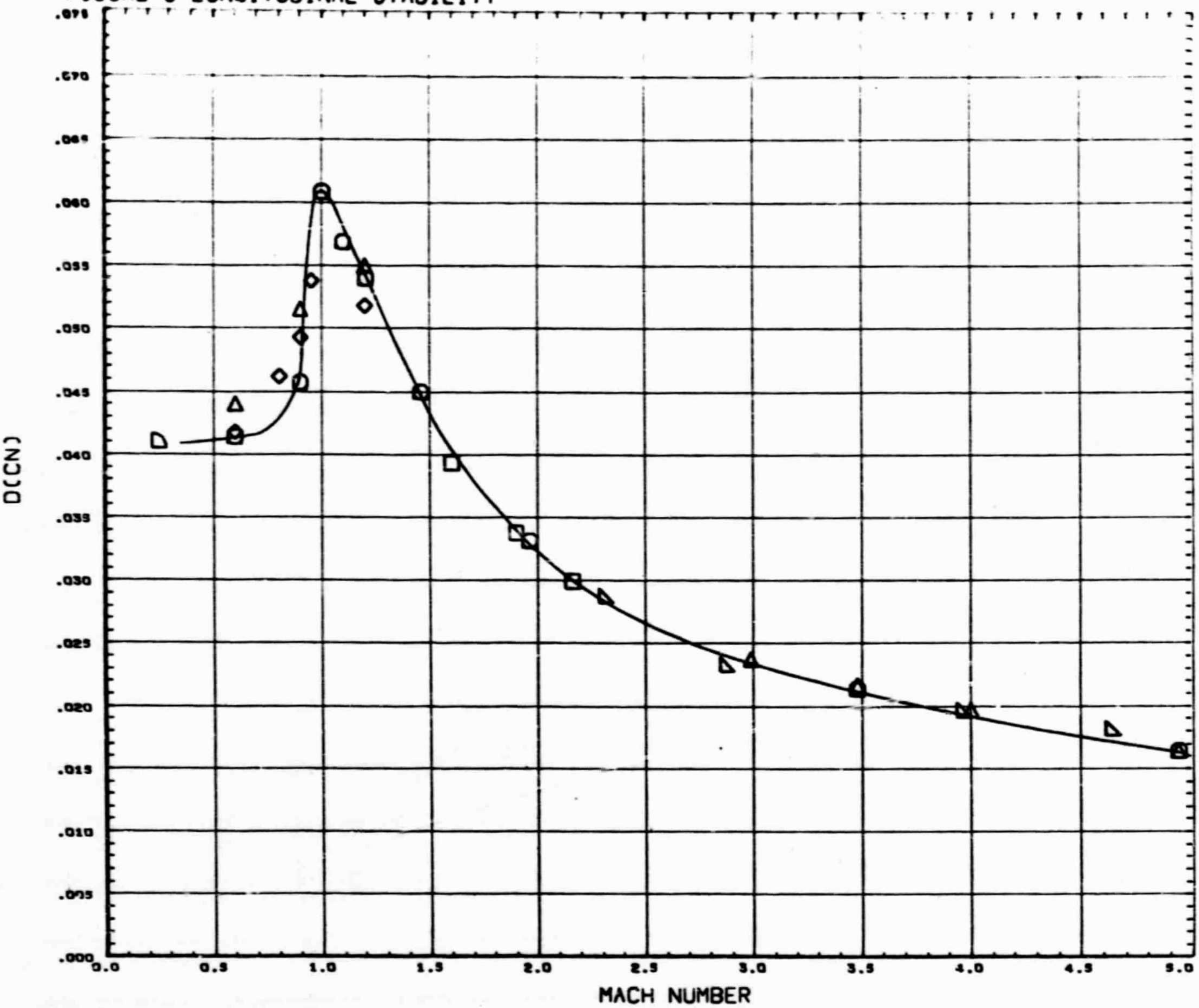
FIGURE 2. SCALED REYNOLDS NUMBER VS MACH NUMBER FOR THE GAC H-33 ORBITER

FIGURE 3 LONGITUDINAL STABILITY



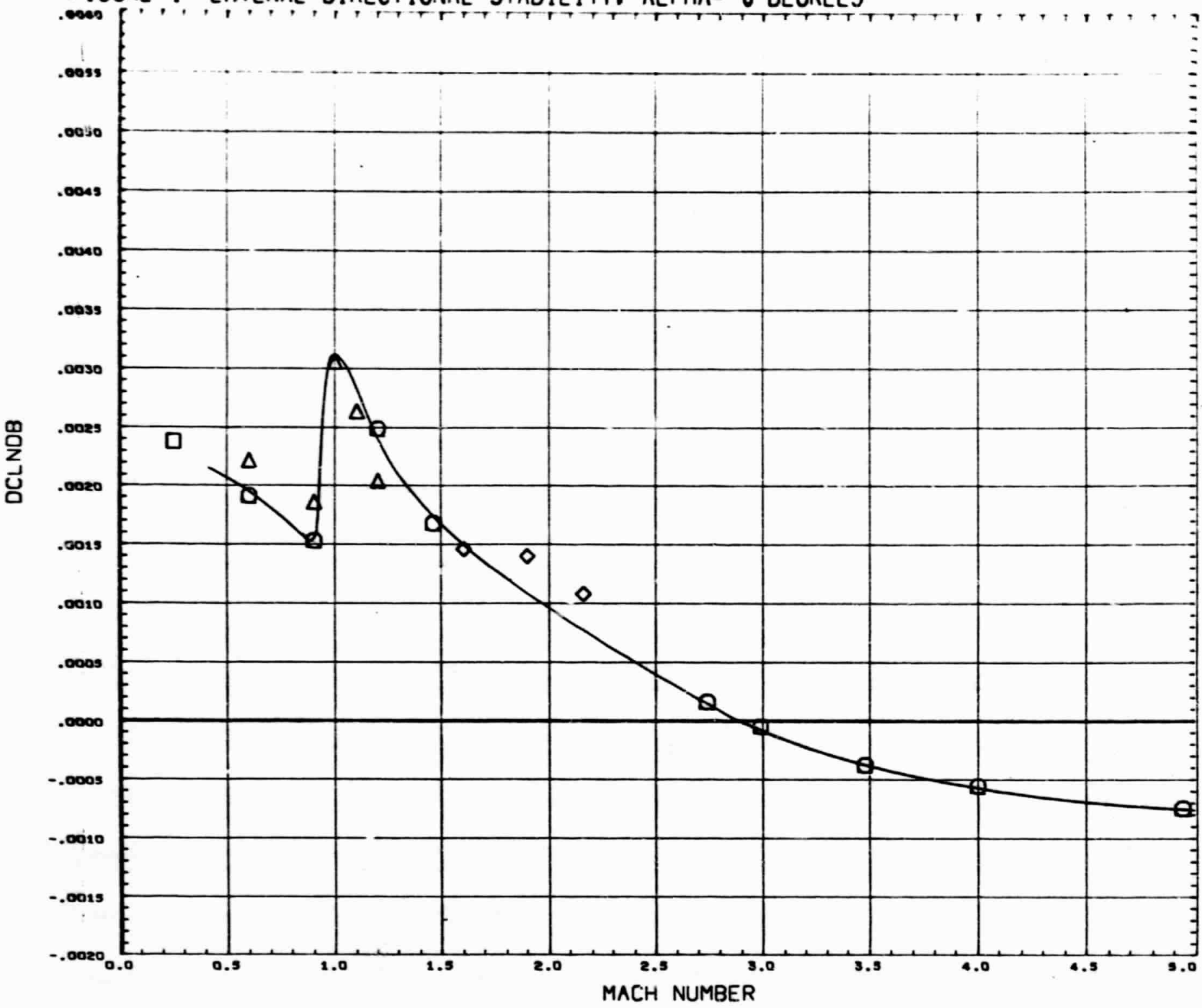
DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	ELEVTR	AILRON	RUDDER	RUDFLR	
(B46021)	○	MSFC 504 GRUMMAN H33 ORB.-DROP TANK3 02	0.000	0.000	0.000	0.000	SEE THE ASSOCIATED DATA
(B49508)	△	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000	0.000	DOCUMENT FOR REFERENCE
(BMNT01)	◇	LARC 8'TPT-604 GAC H-33 W4B5V5	0.000	0.000	0.000	0.000	CHARACTERISTICS
(BMNU02)	□	LARC UPWT 964 GAC H33 W4B5V5 (UPRIGHT)	0.000	0.000	0.000	0.000	
(BMO001)	◺	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	0.000	0.000	30.000	
(DMNL07)	D	LARC LTPT 75 GAC H-33 ORB W4B5V5	0.000	0.000	0.000	0.000	

FIGURE 3 LONGITUDINAL STABILITY



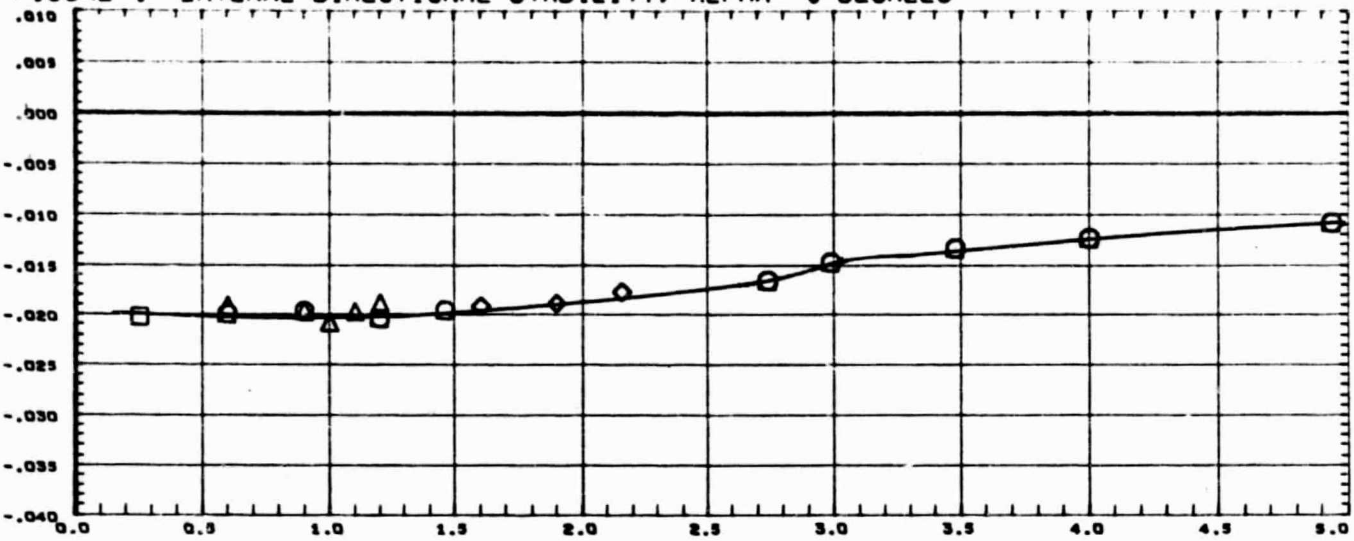
DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	ELEVTR	AILRON	RUDDER	RUDFLR	
(B46021)	○	MSFC 504 GRUMMAN H33 ORB.-DROP TANKS 02	0.000	0.000	0.000	0.000	SEE THE ASSOCIATED DATA
(B49506)	△	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000	0.000	DOCUMENT FOR REFERENCE
(BMNT01)	◇	LARC 8'TPT-604 GAC H-33 W4B5V5	0.000	0.000	0.000	0.000	CHARACTERISTICS
(BMNU02)	□	LARC UPWT 964 GAC H33 W4B5V5 (UPRIGHT)	0.000	0.000	0.00C	0.000	
(BMO001)	⊿	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	0.000	0.000	30.000	
(DMNL07)	D	LARC LTPT 75 GAC H-33 ORB W4B5V5	0.000	0.000	0.000	0.000	

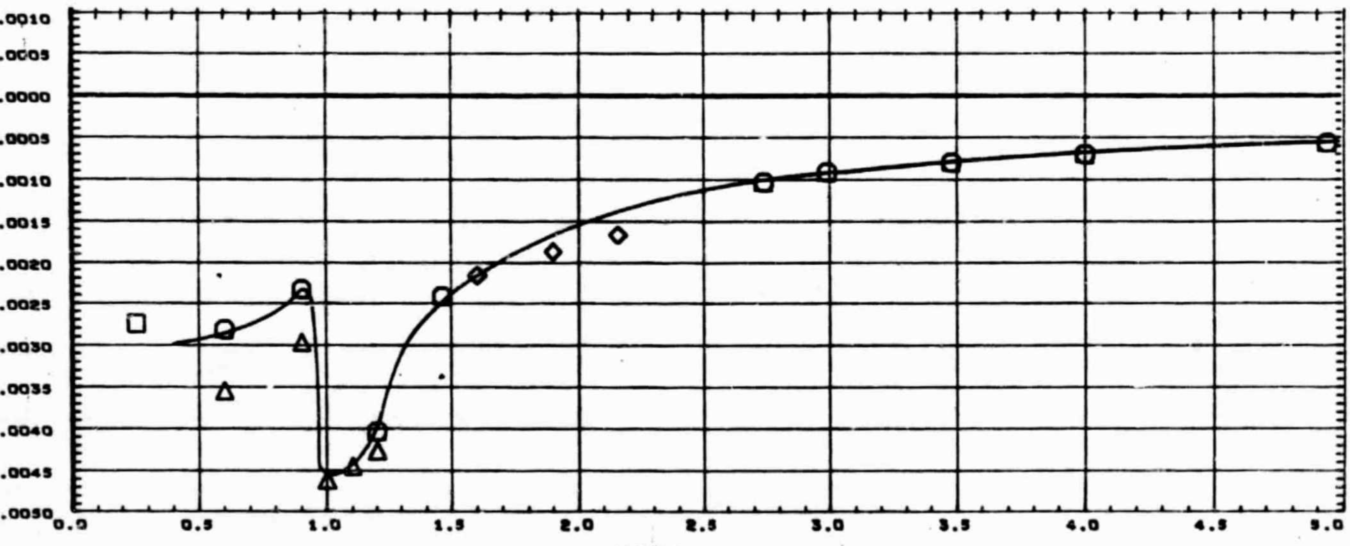
FIGURE 4 LATERAL-DIRECTIONAL STABILITY, ALPHA= 0 DEGREES



DATA SET	SYMBOL	CONFIGURATION DESCRIPTION		ELEVTR	AILRON	RUDDER	RUDFLR	
(D49515)	○	MSFC 507 GAC H-33 ORB. B5W4V5		0.000	0.000	0.000	0.000	SEE THE ASSOCIATED DATA
(D46022)	△	MSFC 504 GRUMMAN H33 ORB.-DROP TANKS	02	0.000	0.000	0.000	0.000	DOCUMENT FOR REFERENCE
(DMNU04)	◇	LARC UPWT 964 GAC H33 W4B5V5		0.000	0.000	0.000	0.000	CHARACTERISTICS
(GMNL07)	□	LARC LTPT 75 GAC H-33 ORB W4B5V5		0.000	0.000	0.000	0.000	

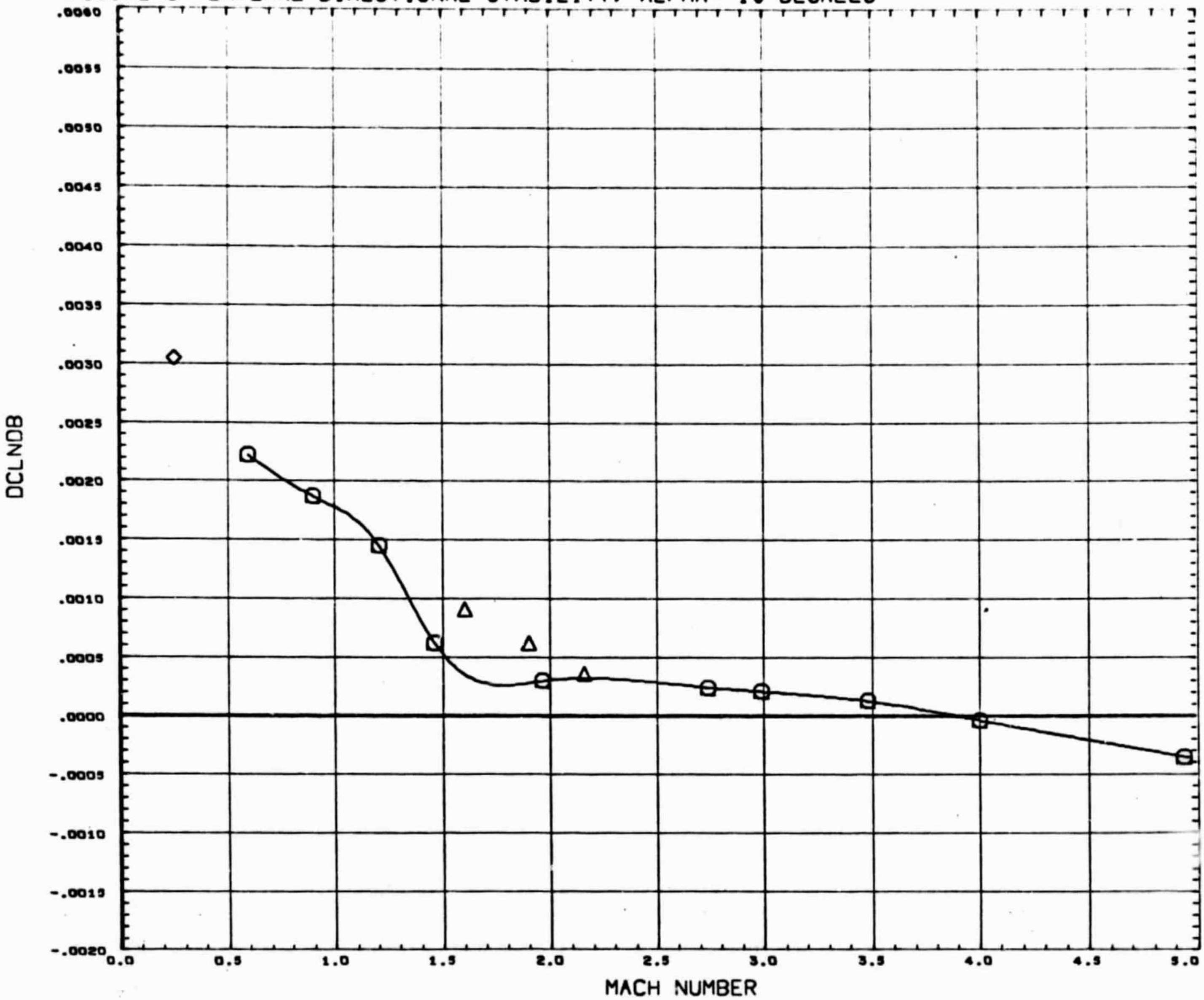
FIGURE 4 LATERAL-DIRECTIONAL STABILITY, ALPHA= 0 DEGREES





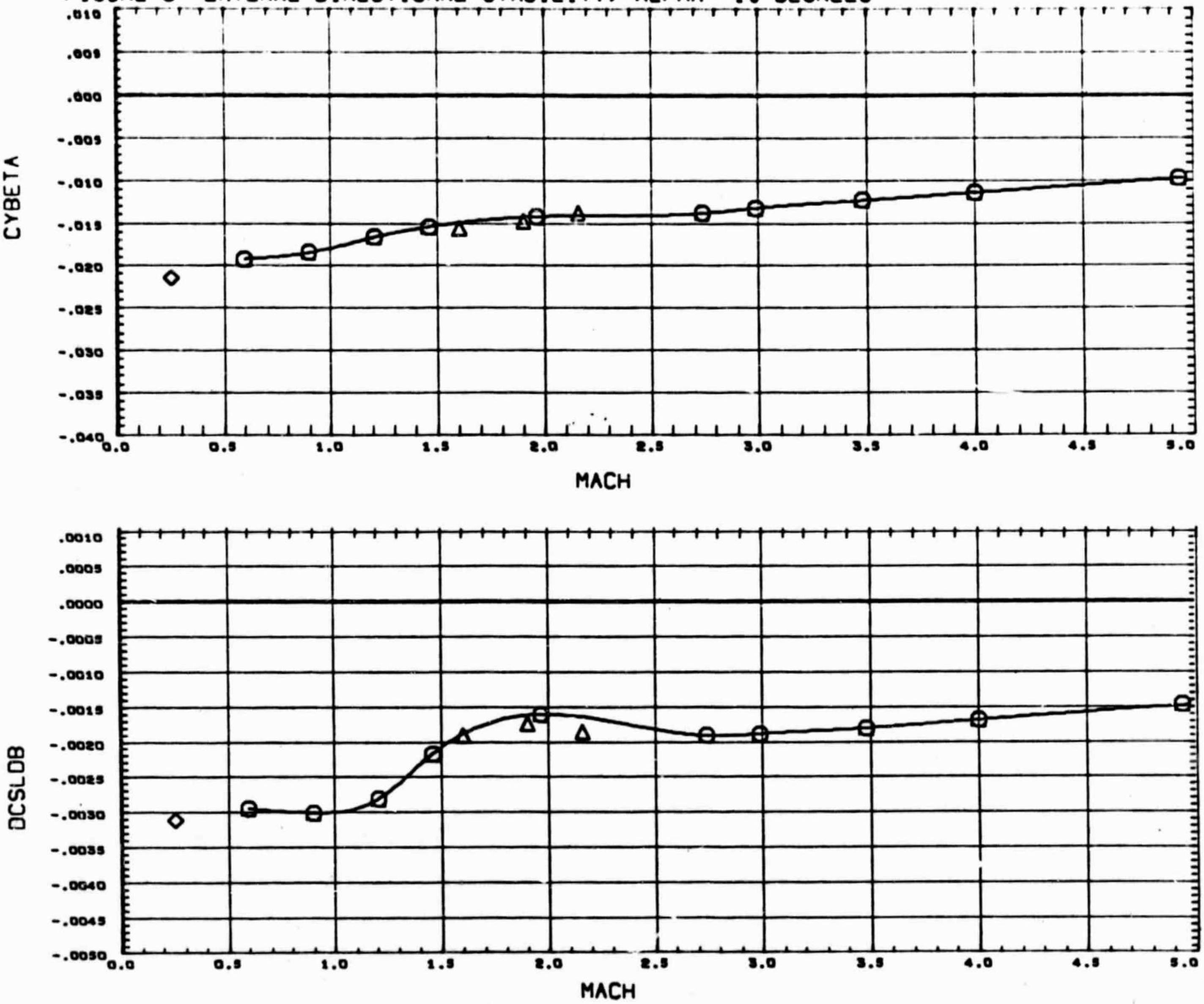
A SET	SYMBOL	CONFIGURATION DESCRIPTION		ELEVTR	AILRON	RUDDER	RUDFLR	
9515)	○	MSFC 507 GAC H-33 ORB. B5W4V5		0.000	0.000	0.000	0.000	SEE THE ASSOCIATED DATA
6022)	△	MSFC 504 GRUMMAN H33 ORB.-DROP TANKS	02	0.000	0.000	0.000	0.000	DOCUMENT FOR REFERENCE
NU04)	◇	LARC UPWT 964 GAC H33 W4B5V5		0.000	0.000	0.000	0.000	CHARACTERISTICS
NL07)	□	LARC LTPT 75 GAC H-33 ORB W4B5V5		0.000	0.000	0.000	0.000	

FIGURE 5 LATERAL-DIRECTIONAL STABILITY, ALPHA= 10 DEGREES



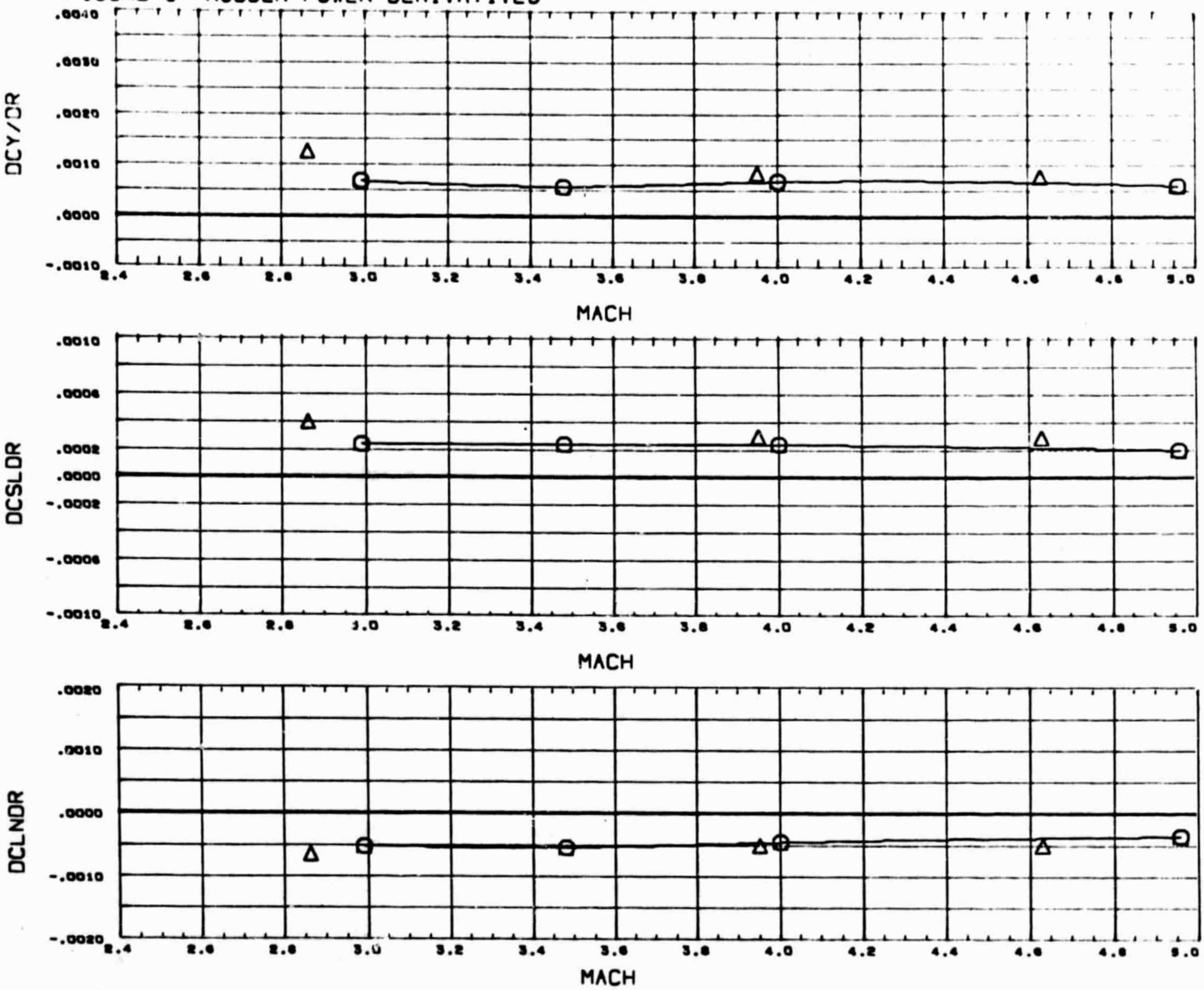
DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	ELEVTR	AILRON	RUDDER	RUDFLR	
(D49029)	○	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000	0.000	SEE THE ASSOCIATED DATA
(DMNU05)	△	LARC UPWT 964 GAC H33 W4B5V5	0.000	0.000	0.000	0.000	DOCUMENT FOR REFERENCE
(HMNL07)	◇	LARC LTPT 75 GAC H-33 ORB W4B5V5	0.000	0.000	0.000	0.000	CHARACTERISTICS

FIGURE 5 LATERAL-DIRECTIONAL STABILITY, ALPHA= 10 DEGREES



DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	ELEVTR	AILRON	RUDDER	RUDFLR	
(D49029)	○	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000	0.000	SEE THE ASSOCIATED DATA
(DMNU05)	△	LARC UPWT 964 GAC H33 W4B5V5	0.000	0.000	0.000	0.000	DOCUMENT FOR REFERENCE
(HMNL07)	◇	LARC LTPT 75 GAC H-33 ORB W4B5V5	0.000	0.000	0.000	0.000	CHARACTERISTICS

FIGURE 6 RUDDER POWER DERIVATIVES

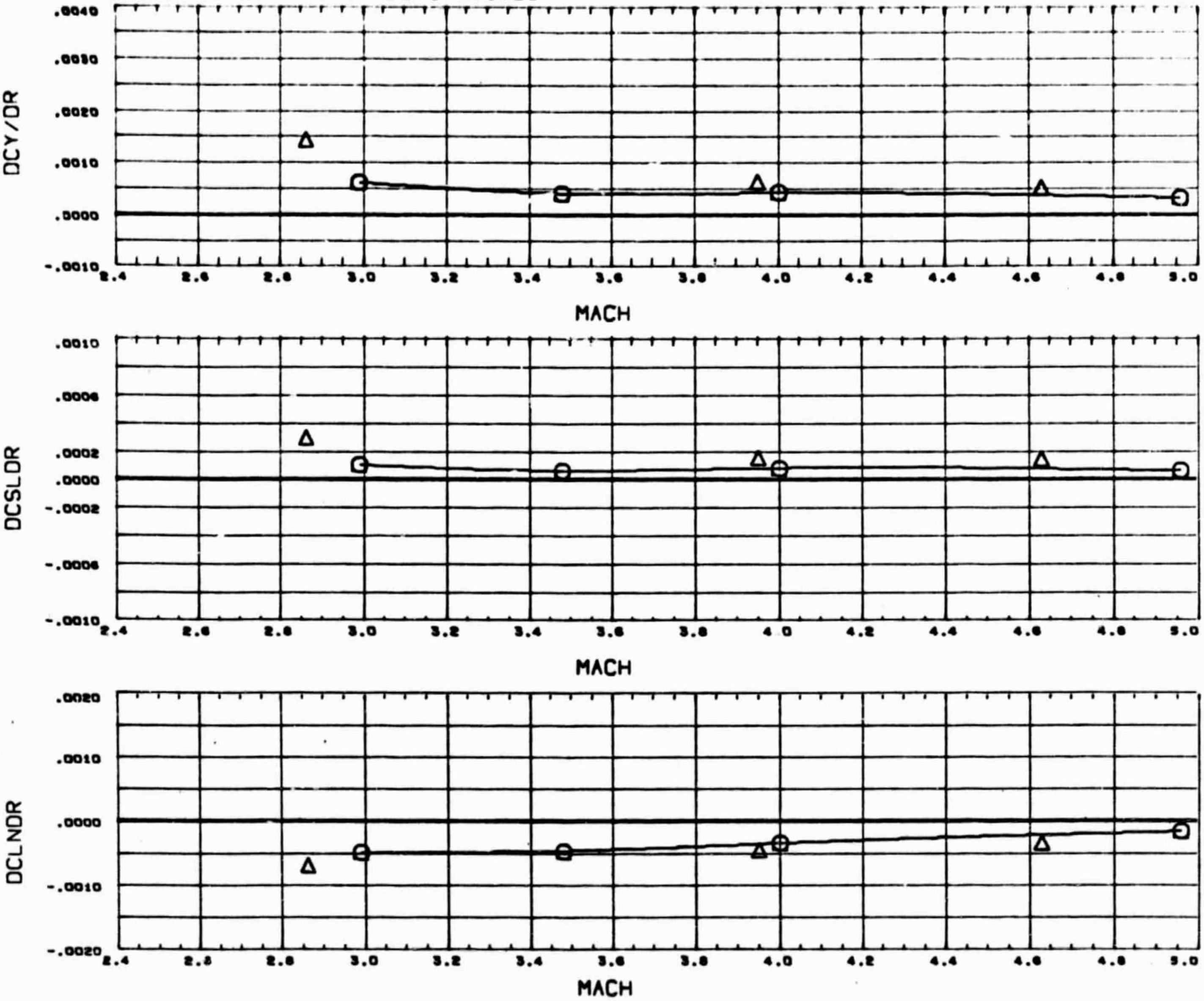


DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	ELEVTR	RUDFLR
(E49002)	O	MSFC 907 GAC H-33 ORB. B5W4V5	0.000	-10.000	30.000
(EN0003)	Δ	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	-10.000	30.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA .00

FIGURE 6 RUDDER POWER DERIVATIVES

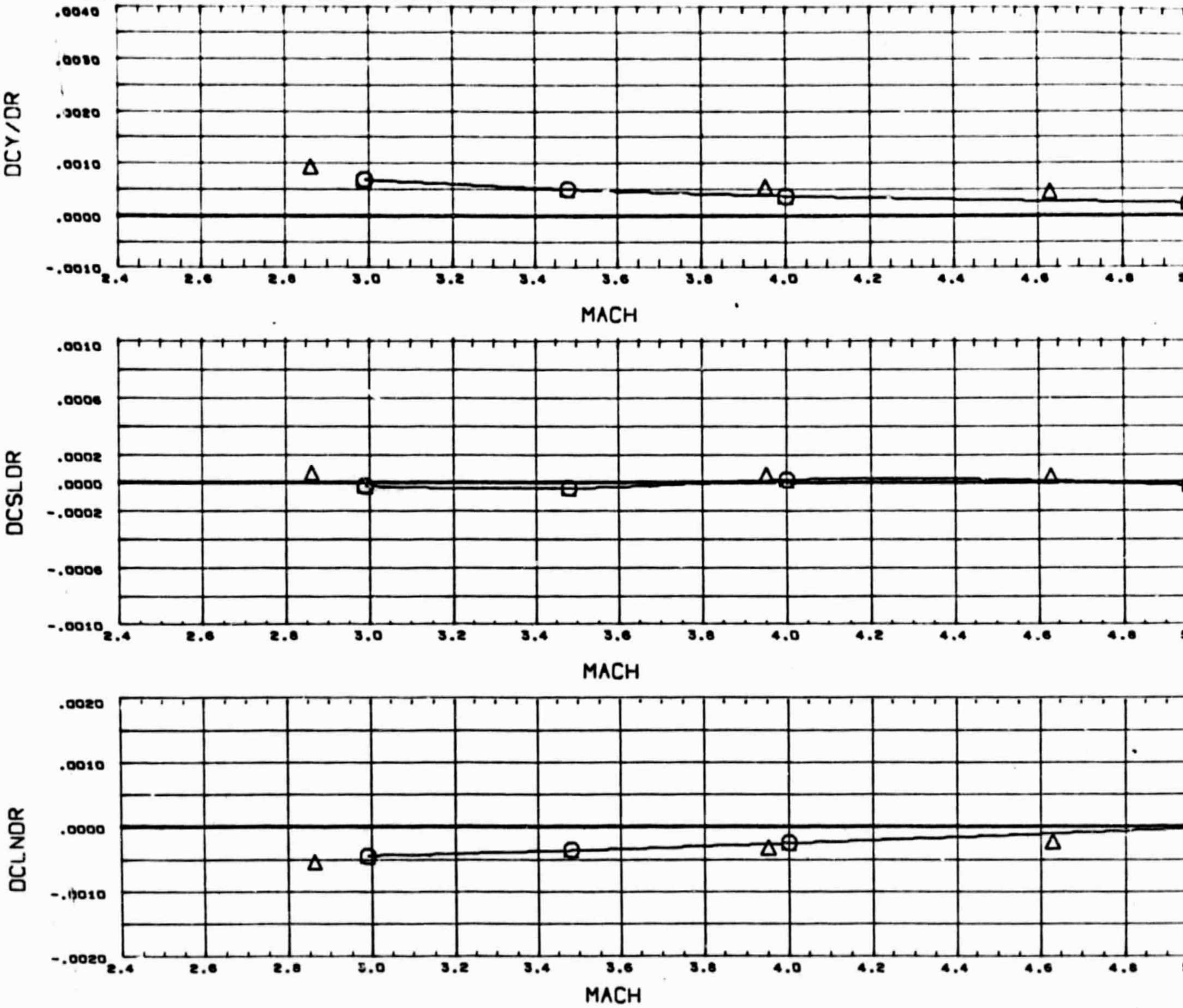


DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	ELEVTR	RUDFLR
(E49002)	O	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	-10.000	30.000
(EMOD03)	Δ	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	-10.000	30.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA 10.00

FIGURE 6 RUDDER POWER DERIVATIVES

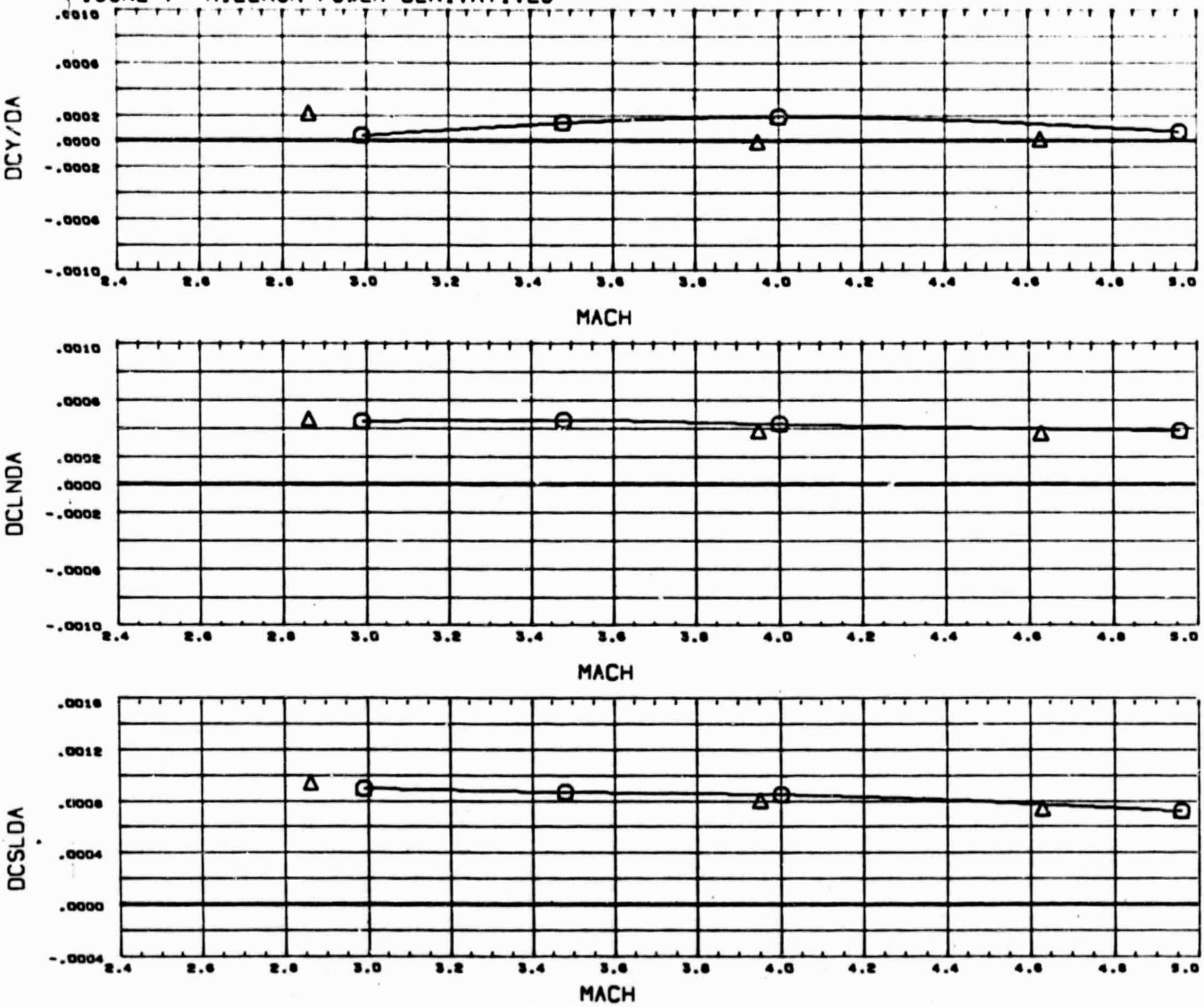


DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	ELEVTR	RUDFLR
(E49002)	O	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	-10.000	30.000
(EM0003)	Δ	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	-10.000	30.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA 20.00

FIGURE 7 AILERON POWER DERIVATIVES

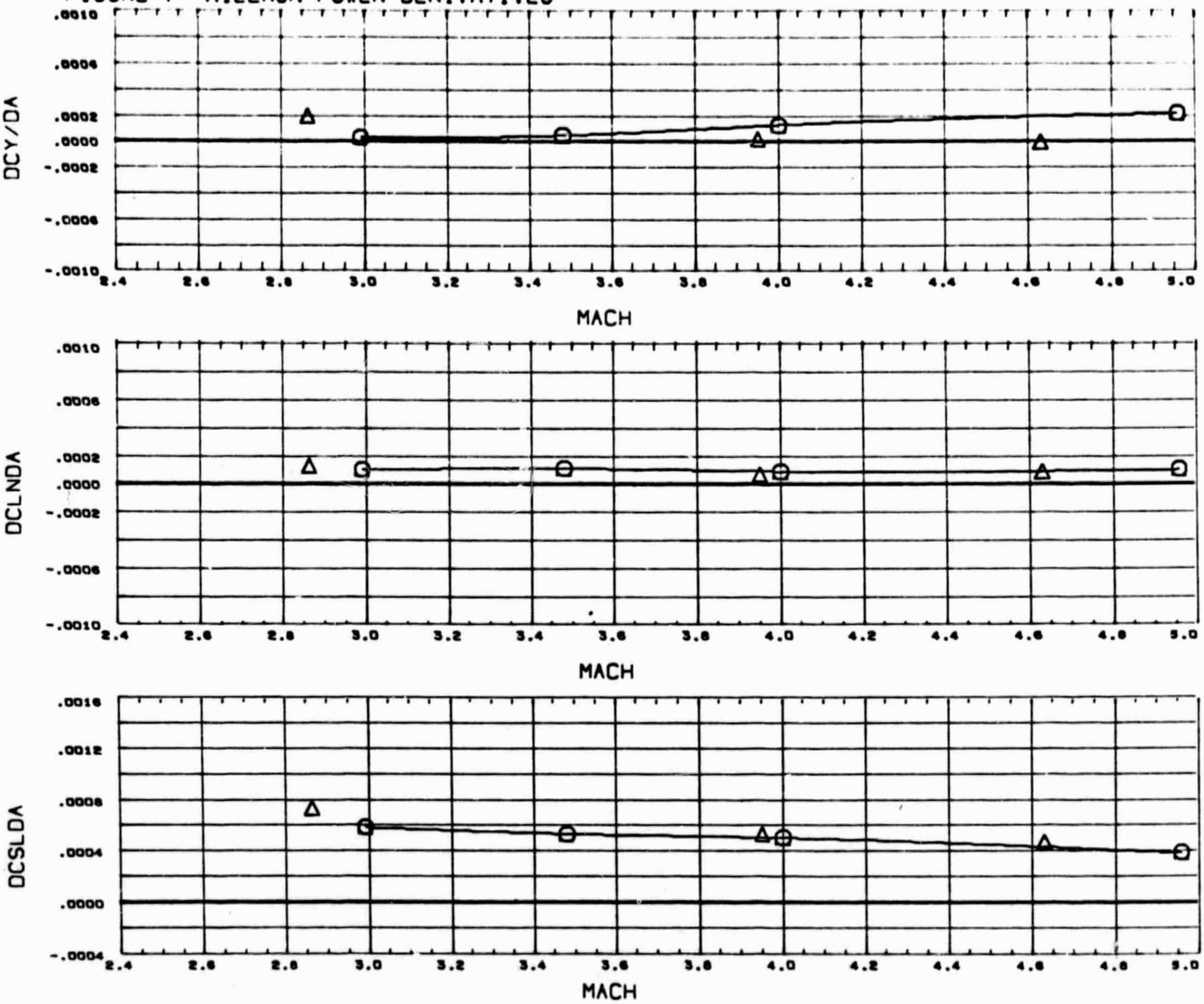


DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	ELEVTR	RUDFLR
(E49003)	○	MSFC 907 GAC H-33 ORB. 85W4V5	0.000	-20.000	30.000
(EM0004)	△	LARC UPWT 964/969 GAC H-33 ORBITER 85W4V5	0.000	-20.000	30.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA .00

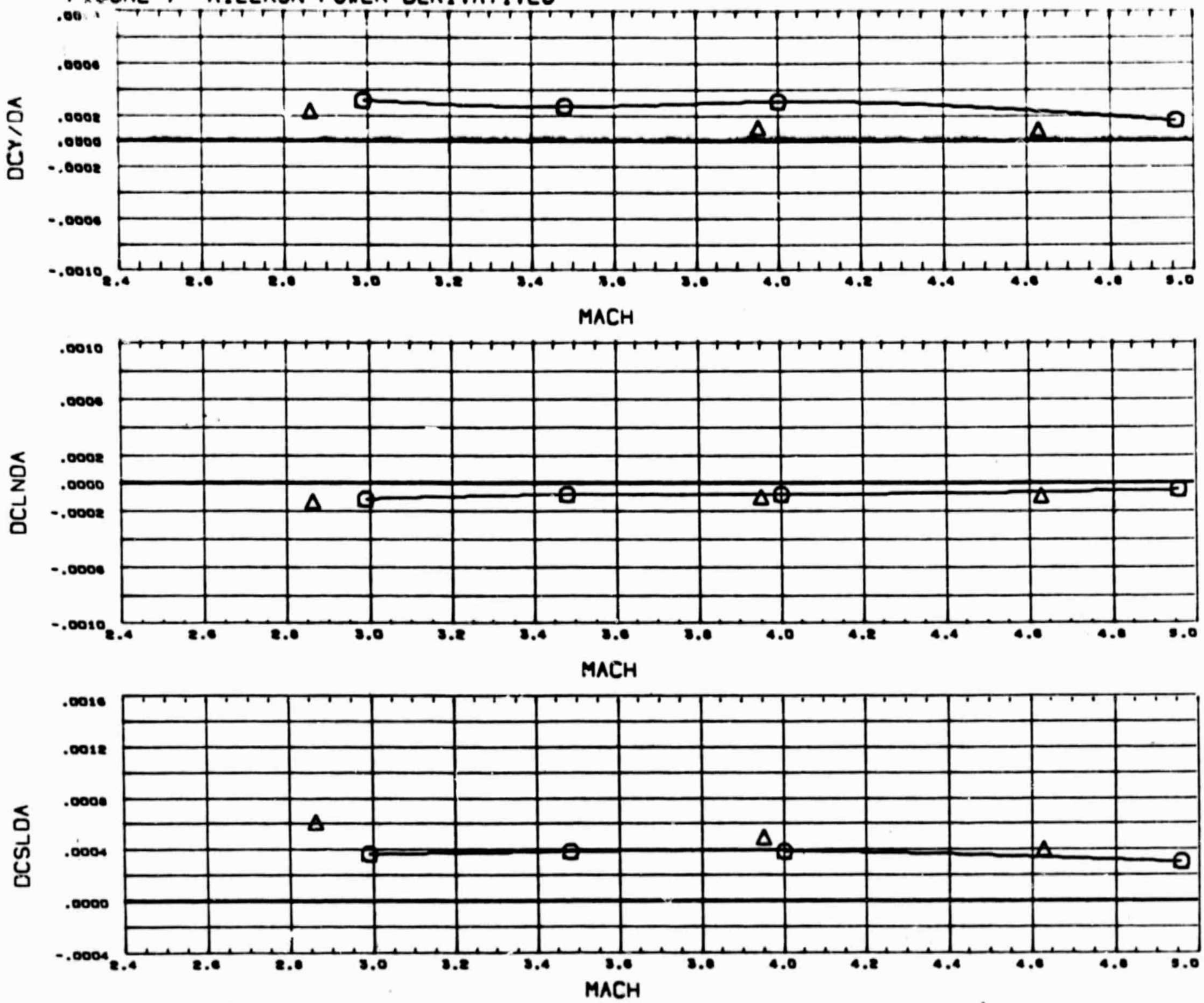
FIGURE 7 AILERON POWER DERIVATIVES



DATA SET SYMBOL CONFIGURATION DESCRIPTION BETA ELEVTR RUDFLR
(E49003) ○ MSFC 507 GAC H-33 ORB. B5W4V5 0.000 -20.000 30.000
(EM0004) △ LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5 0.000 -20.000 30.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

FIGURE 7 AILERON POWER DERIVATIVES

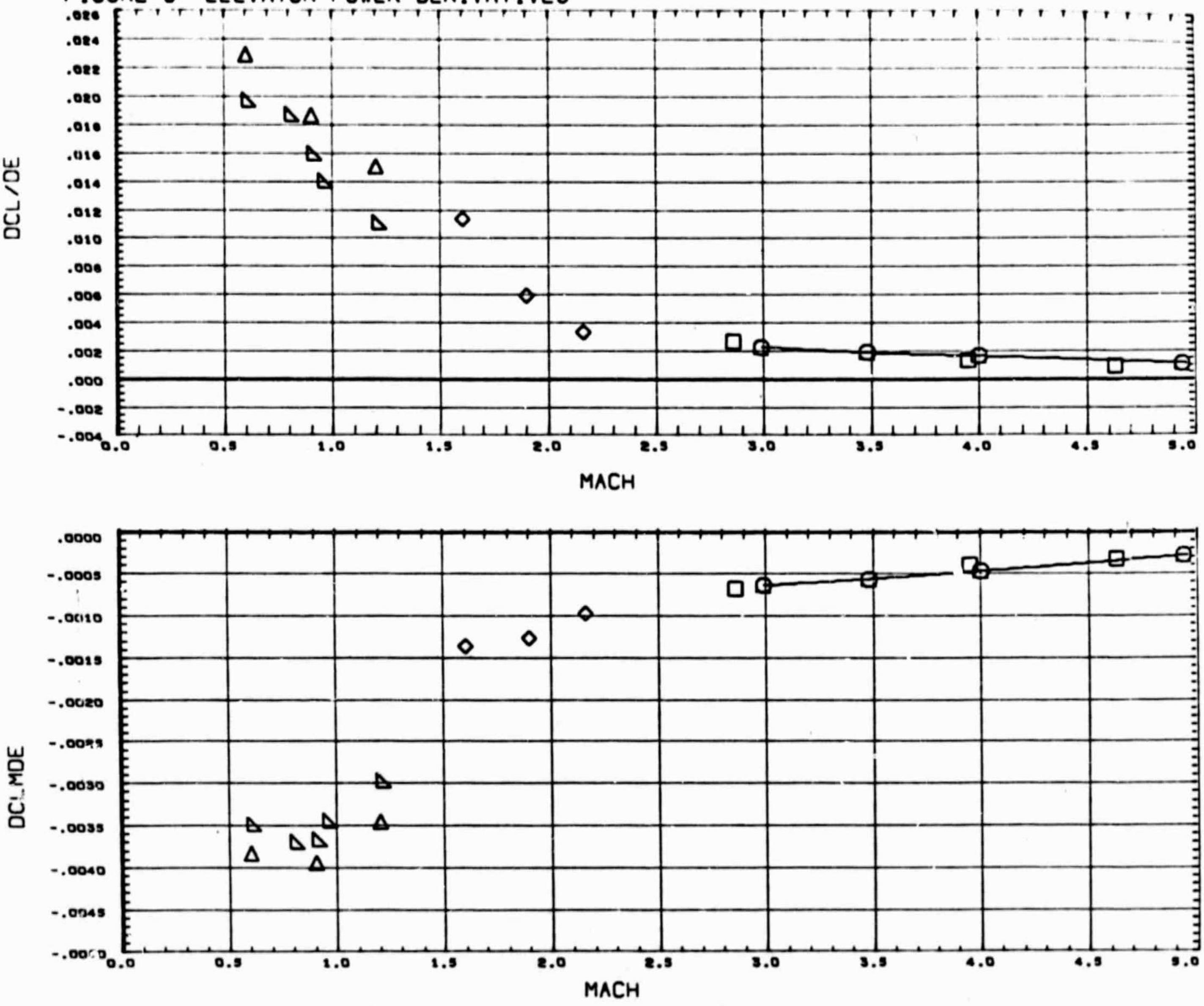


DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	ELEVTR	RUDFLR
(E49003)	O	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	-20.000	30.000
(EH0004)	Δ	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	-20.000	30.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA 20.00

FIGURE 8 ELEVATOR POWER DERIVATIVES

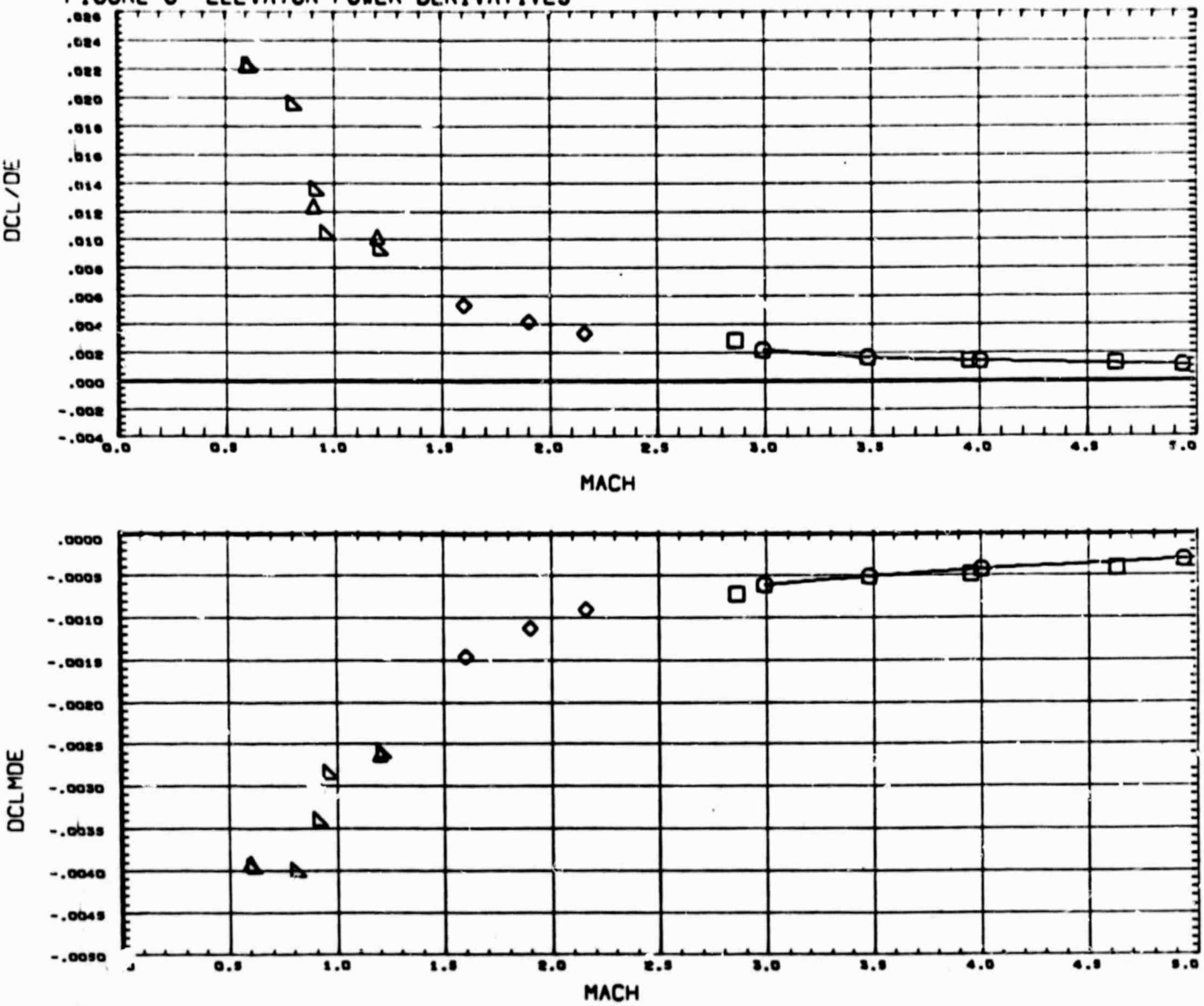


DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	RUDDER	RUDFLR
(E49001)	○	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	30.000
(E49036)	△	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000
(EHNU08)	◇	LARC UPWT 964 GAC H-33 ORB. B5W4V5	0.000	0.000	30.000
(E40001)	□	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	0.000	30.000
(EHNT01)	◺	LARC 8'TPT-604 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA .00

FIGURE 8 ELEVATOR POWER DERIVATIVES

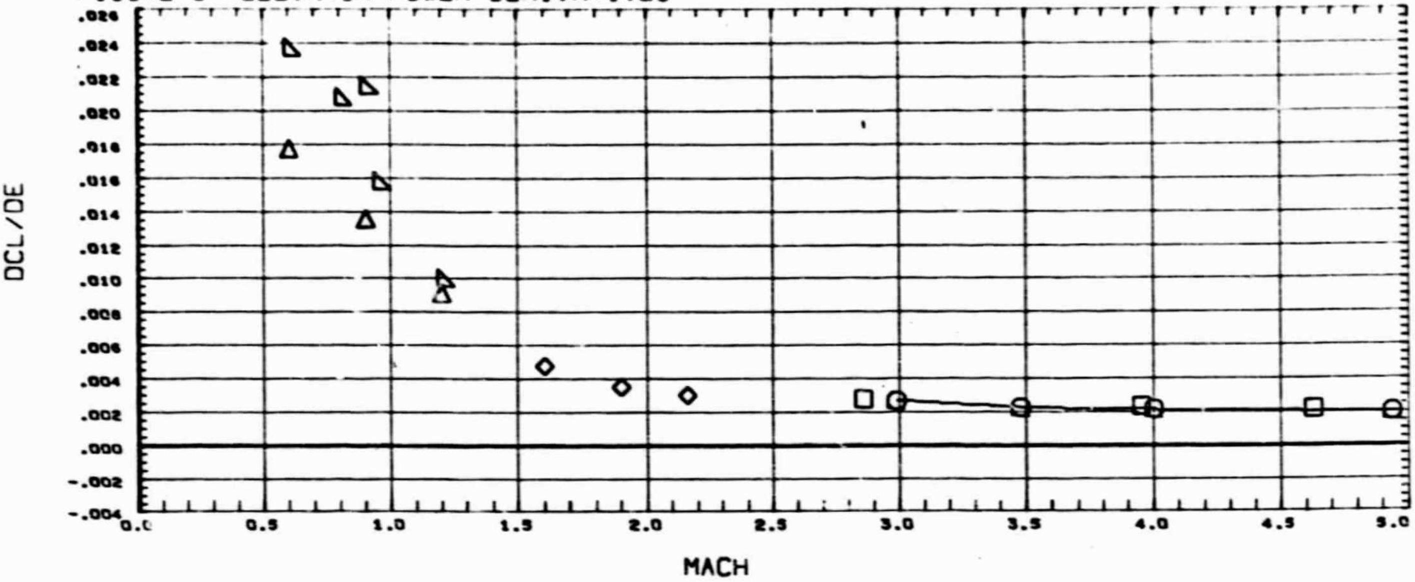


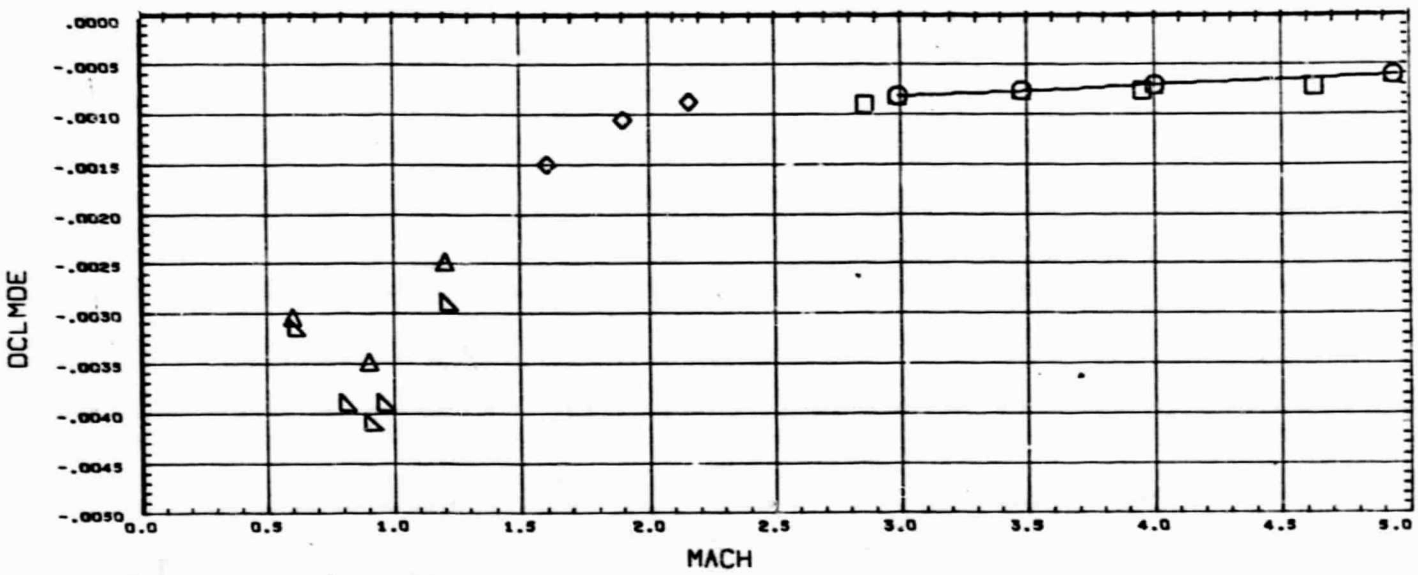
DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	RUDDER	RUDFLR
(E49001)	○	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	30.000
(E49036)	△	MSFC 507 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000
(ENHU08)	◇	LARC UPWT 964 GAC H-33 ORB. B5W4V5	0.000	0.000	30.000
(ENO001)	□	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	0.000	30.000
(ENNT01)	◺	LARC 8'TPT-604 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS

ALPHA 10.00

FIGURE 8 ELEVATOR POWER DERIVATIVES





DATA SET	SYMBOL	CONFIGURATION DESCRIPTION	BETA	RUDDER	RUDFLR
(E49001)	○	MSFC 507 GAC H-33 ORB B5W4V5	0.000	0.000	30.000
(E49035)	△	MSFC 507 GAC H-33 ORB. B5W4V5	0.[illegible]	0.000	0.000
(ENNU09)	◇	LARC UPWT 964 GAC H-33 ORB. B5W4V5	0.[illegible]	0.000	30.000
(EN0001)	□	LARC UPWT 964/969 GAC H-33 ORBITER B5W4V5	0.000	0.000	30.000
(EMNT01)	◺	LARC 8'TPT-604 GAC H-33 ORB. B5W4V5	0.000	0.000	0.000

SEE THE ASSOCIATED DATA DOCUMENT FOR REFERENCE CHARACTERISTICS .

ALPHA 20.00

Notes:

1. Positive directions of force coefficients moment coefficients, and angles are indicated by arrows.

2. For clarity, origins of wind and stability axes have been displaced from the center of gravity.

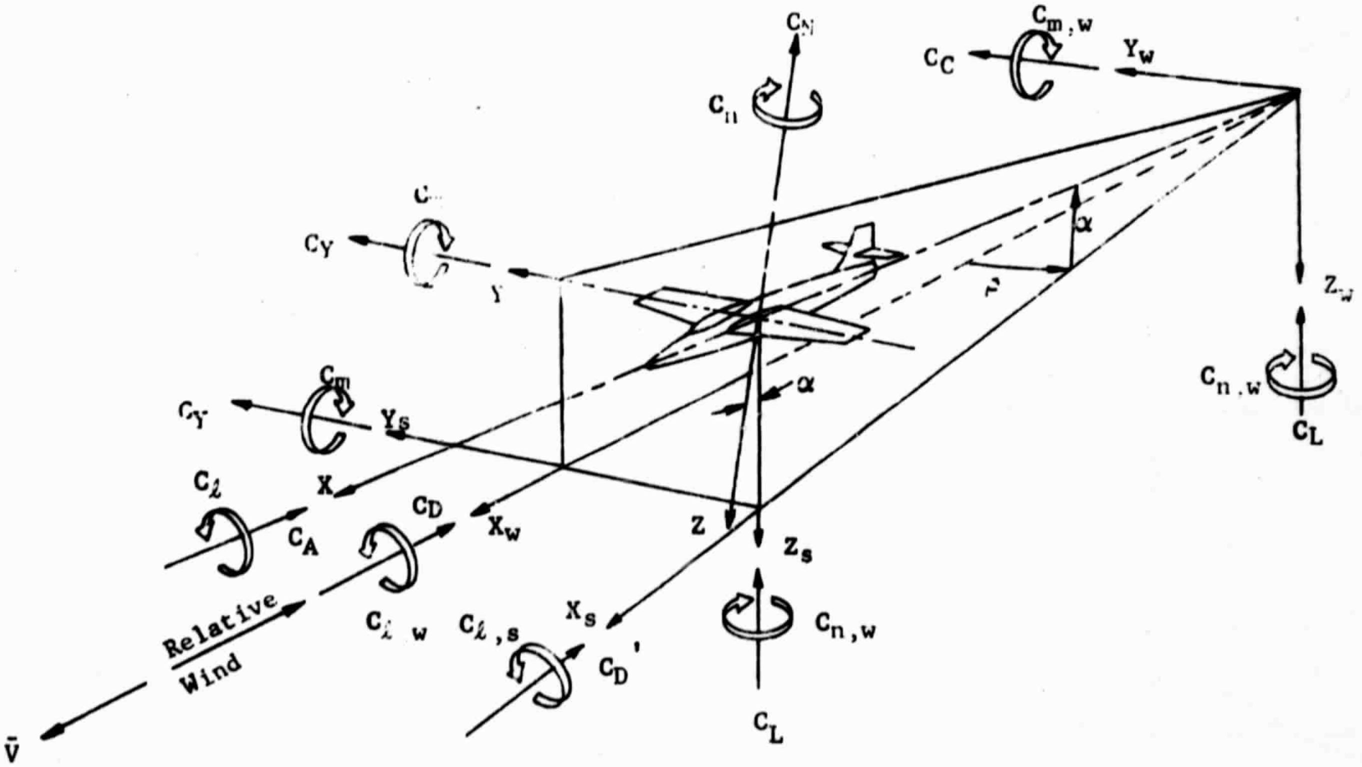


Figure 9. Axis systems, showing direction and sense of force and moment coefficients, angle of attack, and sideslip angle

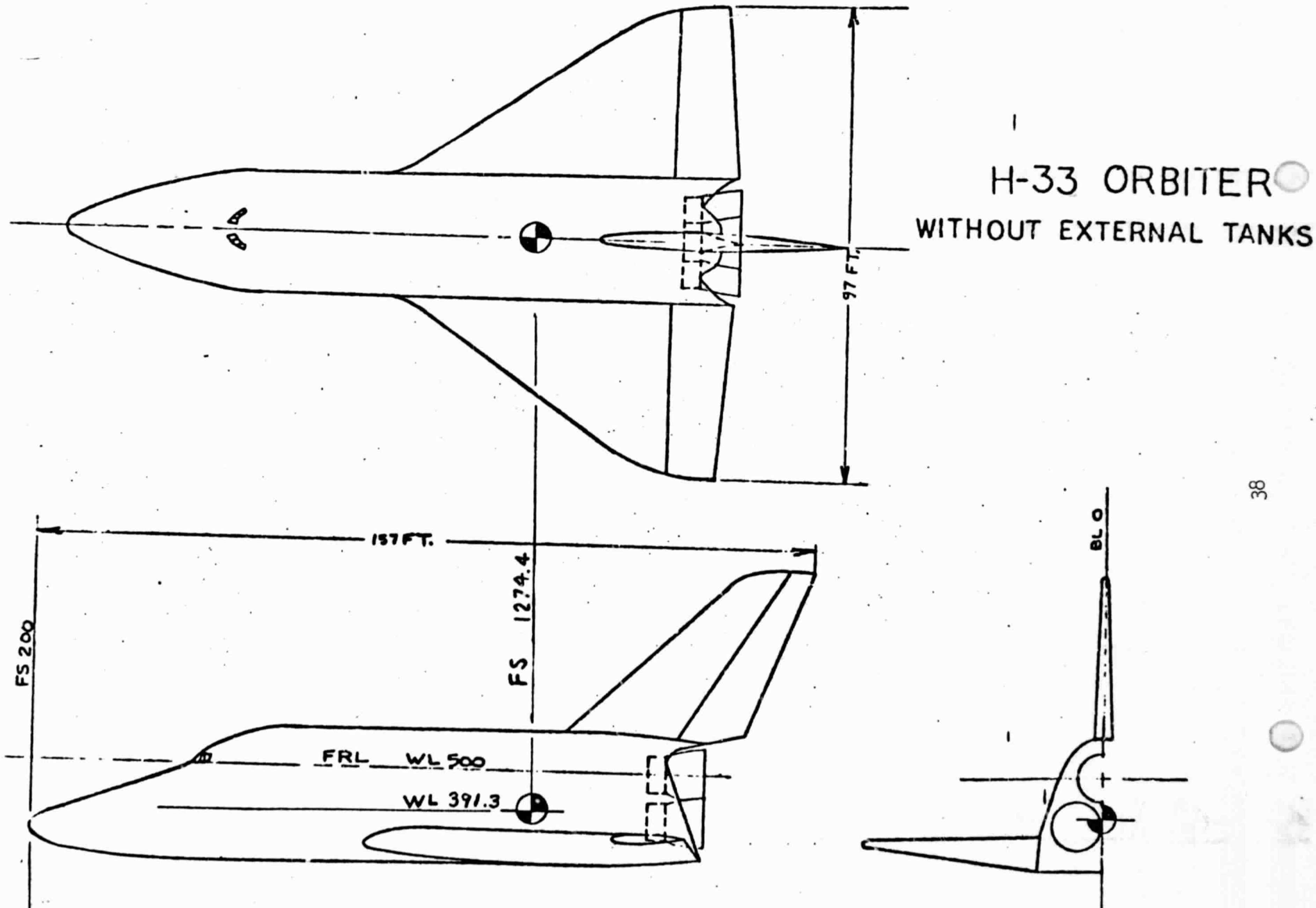


Figure 10. H-33 Orbiter Without External Tanks

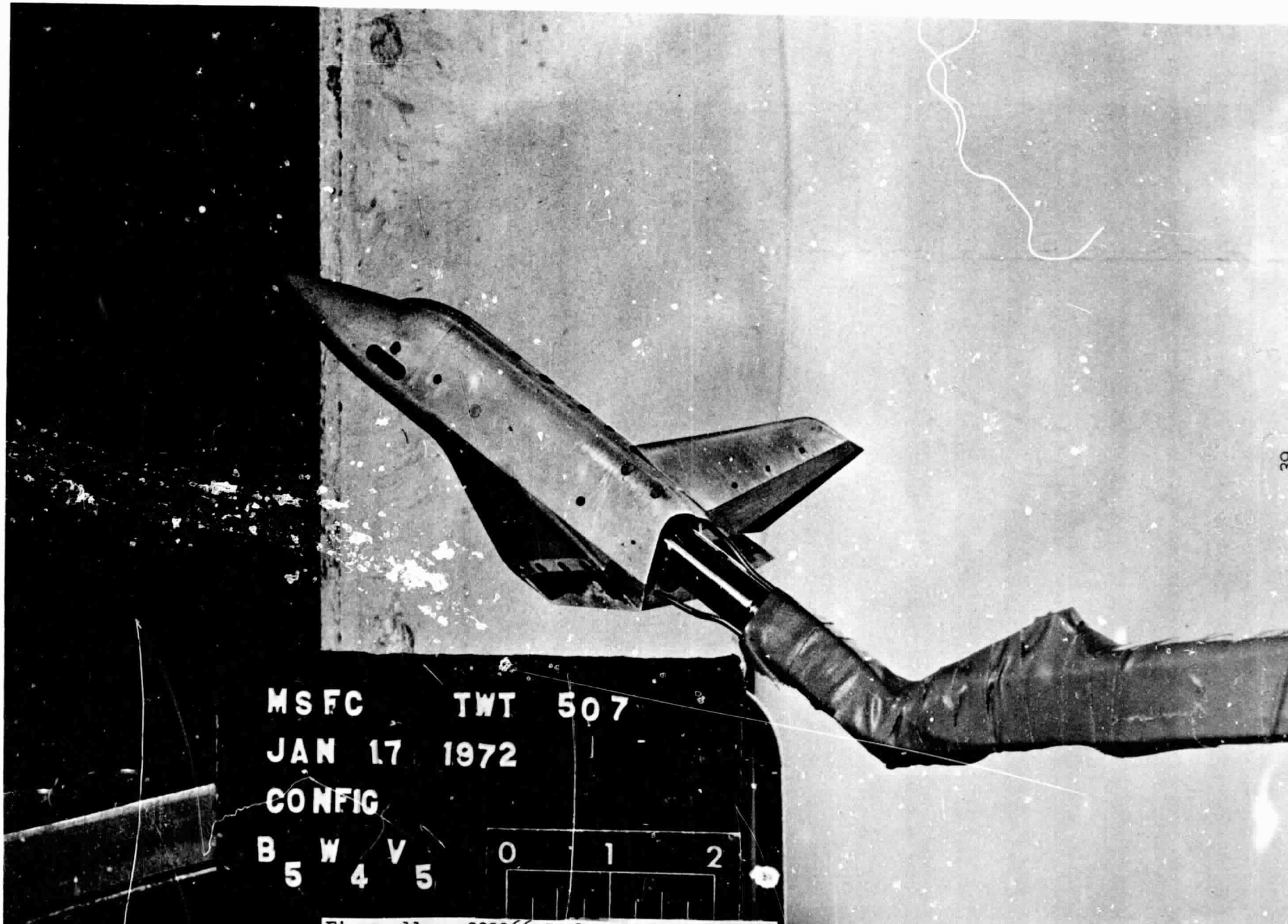


Figure 11. .003366 Scale Model - GAC H-33 Orbiter

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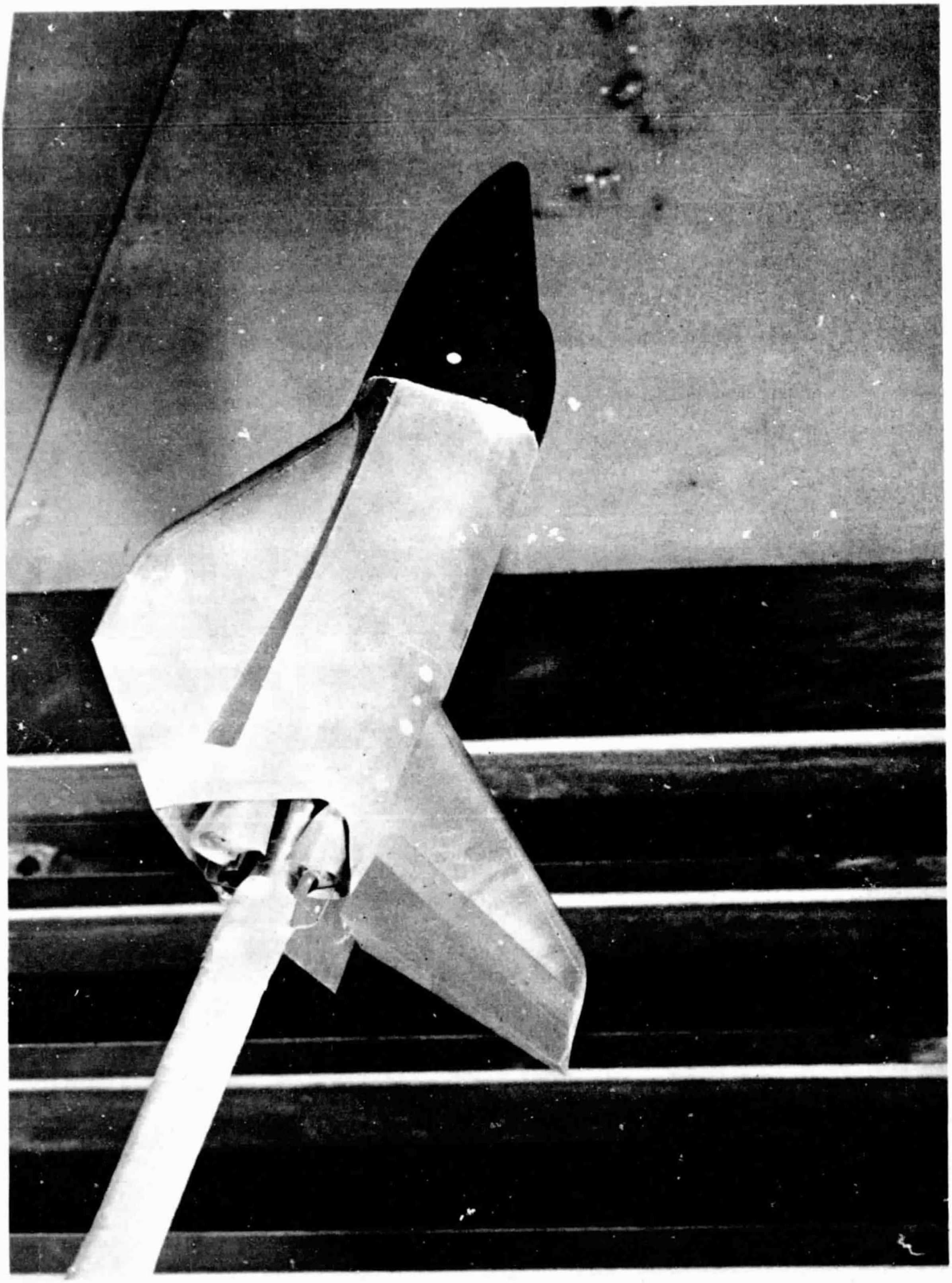
08-2-72



NASA
L-71-7545

CONCLUSIONS

1. The agreement of data among the facilities compared is excellent considering different models were used in some tests, scaled Reynolds numbers were different and transition strips were not used in all tests.

2. The largest differences exist in control effectiveness and these differences could be caused by deflection angles being slightly in error. If more deflection angles had been available, the confidence in control effectiveness data would be higher.

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3. Brownson, J. J., ARC, "Effects of Reynolds Number on the Aerodynamic Stability and Control Characteristics of the MSC Class 040A Space Shuttle Orbiter at Mach Numbers of 0.6 to 1.2," SADSAC TM-X 62,120, April 1972.

4. Buchholz, R. E., "Comparison of Space Shuttle Stability and Control Characteristics Obtained in the MSFC 14-Inch Trisonic Wind Tunnel and Four Other Facilities," Lockheed TM54/20-325, July 1971.

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7. Krepski, R., GAC, "Static Aerodynamic Characteristics and Control Effectiveness of the GAC H-33 Orbiter at Mach Numbers from 0.6 to 4.96," SADSAC CR-120,013, documenting MSFC-14"-507.

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10. Ware, G., LaRC, "Transonic Aerodynamic Characteristics of a GAC H-33 Orbiter (M = 0.6 to 1.2)," SADSAC DMS-DR-1195, documenting LaRC 8-TPT 604.

11. Ware, G., LaRC, "Supersonic Aerodynamic Characteristics of a GAC H-33 Orbiter (M = 1.6 to 2.16)," SADSAC DMS-DR-1196, documenting LaRC UPWT 964.

12. Ware, G., LaRC, "Supersonic Aerodynamic Characteristics of a GAC H-33 Orbiter (M = 2.30 to 4.63)," SADSAC DMS-DR-1216, documenting LaRC UPWT 969.

APPENDIX

MODEL COMPONENT DESCRIPTION SHEETS

TABLE III.
DIMENSIONAL DATA

MODEL COMPONENT: BODY - B_5

GENEPAL DESCRIPTION: BASIC H-33 ORBITER BODY

DRAWING NUMBER:

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.003366 MODEL SCALE (in.or in.^{2})
Length	135	5.453
Max. Width	25	1.010
Max. Depth	27.5	1.111
Fineness Ratio	4.92	4.92
Area		
Max. Cross-Sectional	530	.865
Planform	3120	5.090
Wetted	10,345	16.878
Base	461	.752

TABLE III. (Continued)

MODEL COMPONENT: ℄ VERTICAL TAIL - V_5

GENERAL DESCRIPTION: BASIC H-33 ORBITER VERTICAL TAIL

DRAWING NUMBER:

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.003366 MODEL SCALE (in.or in.^{2})
Area	855	1.395
Span (equivalent)	33.75	1.363
Inb'd equivalent chord	36.66	1.481
Outb'd equivalent chord	14.0	.565
Ratio Elevator chord/horizontal tail chord		
At Inb'd equiv. chord	.348	.348
At Outb'd equiv. chord	.351	.351
Sweep Back Angles, degrees		
Leading Edge	47	47°
Tailing Edge	21.85°	21.85°
Hingeline	32	32°
Area Moment (Normal to hinge line)		
ASPECT RATIO	1.33	1.33
TAPER RATIO	.38	.38
MAC	27	1.091
AIRFOIL SECTION	NACA 64A010	NACA 64A010

Table III (Continued)

MODEL COMPONENT: RUDDER (FOR V_5 VERTICAL TAIL)

GENERAL DESCRIPTION: MOVABLE CONTROL SURFACE ASSOCIATED WITH THE V_5 VERTICAL TAIL

DRAWING NUMBER:

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.003366 MODEL SCALE (in. or in.^{2})
Area	292	.476
Span (equivalent)	34.75	1.404
Inb'd equivalent chord	12.76	.515
Outb'd equivalent chord	4.92	.199
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord		
At Outb'd equiv. chord		
Sweep Back Angles, degrees		
Leading Edge	32	32°
Tailing Edge	21.85°	21.85°
Hingeline	32	32°
Area Moment (Normal to hinge line)		

TABLE III. (Continued)

MODEL COMPONENT: WING - W_4

GENERAL DESCRIPTION: BASIC H-33 ORBITER WING

DRAWING NUMBER:

DIMENSIONS:	FULL-SCALE	.003366 MODEL SCALE
TOTAL DATA	(ft.or ft.^{2})	(in.or in.^{2})
Area		
Planform	4840	7.[illegible]
Wetted	5940	9.[illegible]1
Span (equivalent)	94.5	3.[illegible]7
Aspect Ratio	1.845	1.845
Rate of Taper		
Taper Ratio	.178	.178
Diehedral Angle, degrees	5°	5°
Incidence Angle, degrees	2°@body-3°@tip	2°@body-3°@ tip
Aerodynamic Twist, degrees		
Toe-In Angle		
Cant Angle		
Sweep Back Angles, degrees		
Leading Edge	55°	55°
Trailing Edge	-5°	-5°
0.25 Element Line	46.32°	46.32°
Chords:		
Root (Wing Sta. 0.0)	86.96	3.512
Tip, (equivalent)	15.48	.625
MAC,	59.5	2.403
Fus. Sta. of .25 MAC		
W.P. of .25 MAC		
Airfoil Section		
Root	t/c=9.5%cambered sect.	t/c=95%cambered sect.
Tip	" " "	" " "
EXPOSED DATA		
Area	2900	4.731
Span, (equivalent)	69.5	2.807
Aspect Ratio	1.666	1.666
Taper Ratio	.228	.228
Chords		
Root	67.98	2.746
Tip	15.48	.625
MAC	47.2	1.907
Fus. Sta. of .25 MAC		
W.P. of .25 MAC		

TABLE III. (Continued)

MODEL COMPONENT: ELEVON (FOR W_4 WING)

GENERAL DESCRIPTION: INDIVIDUAL MOVABLE CONTROL SURFACE ASSOCIATED WITH THE W_4 WING

DRAWING NUMBER:

DIMENSIONS:	FULL-SCALE ($ft.$ or $ft.^2$)	.003366 MODEL SCALE ($in.$ or $in.^2$)
Area	410	.669
Span (equivalent)	34.75	1.404
Inb'd equivalent chord	13.6	.549
Outb'd equivalent chord	10.0	.404
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord		
At Outb'd equiv. chord		
Sweep Back Angles, degrees		
Leading Edge	0°	0°
Tailing Edge	-5°	-5°
Hingeline	0°	0°
Area Moment (Normal to hinge line)		

Table III (Continued)

MODEL COMPONENT: BODY - B_5

GENERAL DESCRIPTION: Basic H-33 Orbiter Body

DRAWING NUMBER: 518 MOD 1210, 518 MOD 1211

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.0148148 MODEL SCALE (1/67.5) (in. or in.^{2})
Length	135	24
Max. Width	25	4.444
Max. Depth	27.5	4.889
Fineness Ratio	4.92	4.92
Area		
Max. Cross-Sectional	530	16.751
Planform	3120	98.607
Wetted	10.345	326.953
Base	461	14.570

Table III (Continued)

MODEL COMPONENT: RUDDER (FOR V_5 VERTICAL TAIL)

GENERAL DESCRIPTION: MOVABLE CONTROL SURFACE ASSOCIATED WITH THE V_5 VERTICAL TAIL

DRAWING NUMBER: 518 MOD 1210, 518 MOD 1213, 518 MOD 1214

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.0148148 MODEL SCALE (1/67.5) (in. or in.^{2})
Area	292	9.229
Span (equivalent)	34.75	6.178
Inb'd equivalent chord	12.76	2.268
Outb'd equivalent chord	4.92	0.875
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord		
At Outb'd equiv. chord		
Sweep Back Angles, degrees		
Leading Edge	32°	32°
Tailing Edge	21.85°	21.85°
Hingeline	32°	32°
Area Moment (Normal to hinge line)		

Table III (Continued)

MODEL COMPONENT: Wing -W_4

GENERAL DESCRIPTION: Basic H-33 Orbiter Wing

DRAWING NUMBER: 518 MOD 1210, 518 MOD 1212

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	MODEL SCALE (1/67.5) .0148148 (in. or in.^{2})
TOTAL DATA		
Area		
Planform	4840	152.968
Wetted	5940	187.733
Span (equivalent)	94.5	16.8
Aspect Ratio	1.845	1.845
Rate of Taper		
Taper Ratio	.178	.178
Diehedral Angle, degrees	5^o	5^o
Incidence Angle, degrees	2^o@body,-3^o@tip	2^o@body-3^o@tip
Aerodynamic Twist, degrees		
Toe-In Angle		
Cant Angle		
Sweep Back Angles, degrees		
Leading Edge	55^o	55^o
Trailing Edge	-5^o	-5^o
0.25 Element Line	46.32^o	46.32^o
Chords:		
Root (Wing Sta. 0.0)	86.96	15.460
Tip, (equivalent)	15.48	2.752
MAC	59.5	10.578
Fus. Sta. of .25 MAC		
W.P. of .25 MAC		
B.L. of .25 MAC		
Airfoil Section		
Root	t/c=9.5%CAMBERED SECT.	t/c=9.5%CAMBERED SECT
Tip	" " "	" " "
EXPOSED DATA		
Area	2900	91.654
Span, (equivalent)	69.5	12.356
Aspect Ratio	1.666	1.666
Taper Ratio	.228	.228
Chords		
Root	67.98	12.085
Tip	15.48	2.752
MAC	47.2	8.391
Fus. Sta. of .25 MAC		
W.P. of .25 MAC		
B.L. of .25 MAC		

Table III (Continued)

MODEL COMPONENT: ELEVON (FOR W_4 WING)

GENERAL DESCRIPTION: INDIVIDUAL MOVABLE CONTROL SURFACE ASSOCIATED WITH THE W_4 WING

DRAWING NUMBER: 518 MOD 1210, 518 MOD 1212

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.0148148 MODEL SCALE (1/67.5) (in. or in.^{2})
Area	410	12.958
Span (equivalent)	34.75	6.178
Inb'd equivalent chord	13.6	2.418
Outb'd equivalent chord	10.0	1.778
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord		
At Outb'd equiv. chord		
Sweep Back Angles, degrees		
Leading Edge	0°	0°
Tailing Edge	-5°	-5°
Hingeline	0°	0°
Area Moment (Normal to hinge line)		

Table III (Continued)

MODEL COMPONENT: C VERTICAL TAIL-V_5

GENERAL DESCRIPTION: Basic H-33 Orbiter Vertical Tail

DRAWING NUMBER: 518 MOD 1210, 518 MOD 1213

DIMENSIONS:	FULL-SCALE (ft. or ft.^{2})	.0148148 MODEL SCALE (1/67.5) (in. or in.^{2})
Area	855	27.022
Span (equivalent)	33.75	6.0
Inb'd equivalent chord	36.66	6.517
Outb'd equivalent chord	14.0	2.489
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	.348	.348
At Outb'd equiv. chord	.351	.351
Sweep Back Angles, degrees		
Leading Edge	47°	47°
Tailing Edge	21.85°	21.85°
Hingeline	32°	32°
Area Moment (Normal to hinge line)		
ASPECT RATIO	1.33	1.33
TAPER RATIO	.38	.38
MAC	27	4.8
AIRFOIL SECTION	NACA 64A010	

TEST FACILITY DESCRIPTIONS

MSFC 14-IN. TRISONIC WIND TUNNEL

The Marshall Space Flight Center 14" x 14" Trisonic Wind Tunnel is an intermittent blowdown tunnel which operates by high pressure air flowing from storage to either vacuum or atmospheric conditions. A Mach number range from .2 to 5.85 is covered by utilizing two interchangeable test sections. The transonic section permits testing at Mach 0.20 through 2.50, and the supersonic section permits testing at Mach 2.74 through 5.85. Mach numbers between .2 and .9 are obtained by using a controllable diffuser. The range from .95 to 1.3 is achieved through the use of plenum suction and perforated walls. Mach numbers of 1.44, 1.93 and 2.50 are produced by interchangeable sets of fixed contour nozzle blocks. Above Mach 2.50 a set of fixed contour nozzle blocks are tilted and translated automatically to produce any desired Mach number in .25 increments.

Air is supplied to a 6000 cubic foot storage tank at approximately -40°F dew point and 500 psi. The compressor is a three-stage reciprocating unit driven by a 1500 hp motor.

The tunnel flow is established and controlled with a servo actuated gate valve. The controlled air flows through the valve diffuser into the stilling chamber and heat exchanger where the air temperature can be controlled from ambient to approximately 180°F The air then passes through the test section which contains the nozzle blocks and test region.

Downstream of the test section is a hydraulically controlled pitch sector that provides a total angle of attack range of 20° ($\pm$10°). Sting offsets are available for obtaining various maximum angles of attack up to 90°.

LaRC 4-FT. UNITARY PLAN WIND TUNNEL

The NASA LRC 4 foot Unitary Plan Wind Tunnel (UPWT) is a closed-circuit, continuous flow, variable density facility. The test section is 4 feet by 4 feet by 7 feet long.

Two tunnel legs are available for supersonic testing in the Mach number ranges 1.47 to 2.86 (Leg No. 1) and 2.29 to 4.63 (Leg No. 2). All these tests were made in Leg No. 2. An asymmetric, sliding block nozzle position and total pressure setting provide the test Mach numbers at a specified Reynolds number. Reynolds number can be varied from 0.76 to 7.78 million per foot. Available stagnation pressure variation is 4.0 to 142. psia. Dynamic pressure variation is 95. to 1260. psf with normal operating stagnation temperature about 150°F in Mach modes 2 or 3 and about 175°F in Mach mode 4. The tunnel is equipped with a dry air supply, an evacuating system, and a cooling system. The facility power is approximately 83,000 horsepower.

Model mounting provisions consist of various sting arrangements, including axial (longitudinal), lateral (independent pitch and yaw), and roll movement with side wall support. A Schlieren system and oil flow visualization equipment are available. Data are recorded at the tunnel and reduced off-line at the Langley Computer Center. The tunnel is used for force and moment, pressure, and dynamic stability tests. Hot and cold jet effects and heat transfer have been studied in the UPWT.

LaRC 8-FT. TRANSONIC PRESSURE TUNNEL

The Langley 8-foot Transonic Pressure Tunnel is located in Building 640 and is under the direction of the Full-Scale Research Division. The test medium is air. The tunnel has a sting-type model support system with tunnel wall mounts available. It is a single-return closed-circuit tunnel with Mach number continuously variable from 0.2 to 1.3. Stagnation pressure, stagnation temperature, and dewpoint temperature are controlled. Test section is 7.1 foot square. Examples of operating conditions are as follows:

Mach number	0.2 to 0.3	0.4 to 1.0	1.3 to 1.2	1.3
Stagnation pressure, atm	0.25 to 2.0	0.25 to 1.7	0.25 to 1.4	0.25 to 1.0
Stagnation temperature, $^{\circ}R$	580	580	580	580
Dynamic pressure, lb/sq ft	14 to 250	53 to 1333	203 to 1232	226 to 906
Reynolds number per foot	0.3×10^6 3.6×10^6	0.6×10^6 7.0×10^6	1.0×10^6 5.9×10^6	1.0×10^6 4.2×10^6

LaRC LOW TURBULENCE PRESSURE TUNNEL

The NASA Langley Research Center Low Turbulence Pressure Tunnel (LTPT) is a variable-pressure, single return facility with a closed test section 3.5 feet wide and 7 feet high. This facility can be operated at a Reynolds number of 1.0×10^6 to 15.0×10^6 per foot and a Mach number to about 0.4.

TEST CONDITIONS

TABLE IV.

TEST CONDITIONS

TEST MSFC TWT 504

MACH NUMBER	REYNOLDS NUMBER per unit length	DYNAMIC PRESSURE (pounds/sq. inch)	STAGNATION TEMPERATURE (degrees Fahrenheit)
0.6	5.1×10^6	4.4	100
0.9	6.3×10^6	7.4	100
1.0	6.6×10^6	8.2	100
1.1	6.8×10^6	8.7	100
1.2	6.8×10^6	9.2	100
1.46	7.4×10^6	10.8	100
1.96	7.5×10^6	10.9	100
3.50	7.0×10^6	6.8	100
4.96	5.4×10^6	3.07	100

BALANCE UTILIZED: MSFC #201

CAPACITY:		ACCURACY:	COEFFICIENT TOLERANCE:
NF	60#		
SF	20#		
AF	30#		
PM	120 IN-#		
YM	40 IN-#		
RM	25 IN-#		

COMMENTS:

TABLE IV. (Continued)

TEST CONDITIONS

TEST MSFC 507

MACH NUMBER	REYNOLDS NUMBER per unit length	DYNAMIC PRESSURE (pounds/sq. inch)	STAGNATION TEMPERATURE (degrees Fahrenheit)
0.60	5.0×10^6	4.340	98
0.90	6.3×10^6	7.389	96
1.20	6.7×10^6	9.143	97
1.46	7.5×10^6	10.769	95
1.96	7.4×10^6	10.982	112
2.74	4.7×10^6	6.380	138
2.99	5.3×10^6	6.066	103
3.48	7.0×10^6	6.856	104
4.00	8.2×10^6	6.635	104
4.96	5.4×10^6	3.068	103

BALANCE UTILIZED: MSFC No. 201

	CAPACITY:	ACCURACY:	COEFFICIENT TOLERANCE:
NF	60 #	.15 #	Varies with Dynamic Pressure
SF	20 #	.05 #	
AF	30 #	.08 #	
PM	60 in-#	.15 in-#	
YM	20 in-#	.05 in-#	
RM	25 in-#	.06 in-#	

COMMENTS:

Table IV. (Continued)

TEST CONDITIONS
TEST 8 - TPT 604

MACH NUMBER	REYNOLDS NUMBER per unit length	DYNAMIC PRESSURE (pounds/sq. inch)	STAGNATION TEMPERATURE (degrees Fahrenheit)
.6	3.2×10^6	3.0	120°
.8	3.8×10^6	4.3	120°
.9	4.0×10^6	4.9	120°
.95	4.1×10^6	5.2	120°
1.2	4.2×10^6	6.1	120°

BALANCE UTILIZED: LaRC 739

	CAPACITY:	ACCURACY:	COEFFICIENT TOLERANCE:
NF	1200	± 6 #	.014
SF	500	± 2.5#	.006
AF	125	± .6#	.0013
PM	2000	±10 " #	.0009
YM	2000	±10 " #	.0013
RM	1000	± 5 " #	.0006

COMMENTS:

Table IV. (Continued)

TEST CONDITIONS

TEST UPWT 964

MACH NUMBER	REYNOLDS NUMBER per unit length	DYNAMIC PRESSURE (pounds/sq. inch)	STAGNATION TEMPERATURE (degrees Fahrenheit)
1.6	1.7×10^6	2.84	
1.9	1.9×10^6	3.15	
2.16	2.2×10^6	3.58	

BALANCE UTILIZED: LaRC UT 34

	CAPACITY:	ACCURACY:	COEFFICIENT TOLERANCE:
NF	600 #	± 3 #	.007
SF	300 #	± 1.5 #	.0035
AF	50 #	± .25#	.0006
PM	1000 " #	± 5 " #	.0005
YM	600 " #	± 3 " #	.0004
RM	300 " #	± 1.5 " #	.0002

COMMENTS:

Table IV. (Continued)

TEST CONDITIONS
TEST UPWT 969

MACH NUMBER	REYNOLDS NUMBER per unit length	DYNAMIC PRESSURE (pounds/sq. inch)	STAGNATION TEMPERATURE (degrees Fahrenheit)
2.30	2.5×10^6	3.92	
2.86	2.5×10^6	3.44	
3.95	2.5×10^6	2.57	
4.63	2.5×10^6	2.02	

BALANCE UTILIZED: LaRC UT 34

	CAPACITY:	ACCURACY:	COEFFICIENT TOLERANCE:
NF	600 lbs.	± 3 lbs.	
SF	300 lbs.	± 1.5 lbs.	
AF	50 lbs.	± .25 lbs.	
PM	1000 in. lbs.	± 5 in. lbs.	
YM	600 in. lbs.	± 3 in. lbs.	
RM	300 in. lbs.	± 1.5 in. lbs.	

COMMENTS:

TEST CONDITIONS
TEST LTPT 75

MACH NUMBER	REYNOLDS NUMBER per unit length	DYNAMIC PRESSURE (pounds/sq. inch)	[illegible]AGNATION TEMPERATURE ([illegible]renheit)
.25	2.4×10^6	.9	85°
.25	3.9×10^6	1.5	85°
.25	6.0×10^6	2.3	85°
.25	8.0×10^6	3.0	85°
.25	10.0×10^6	3.8	90°
.25	11.4×10^6	4.3	90°
.25	13.4×10^6	4.6	90°

BALANCE UTILIZED: LaRC 832 C

CAPACITY:		**ACCURACY:**	**COEFFICIENT TOLERANCE:** (BASED ON R_N=8.0x10^6)
NF	1000 #	± 5 #	.012
SF	250 #	± 1.25#	.003
AF	85 #	± .43#	.0011
PM	2000 " #	± 10 " #	.0011
YM	1000 " #	± 5 " #	.0007
RM	500 " #	± 2.5"#	.0004

COMMENTS:

Table V.

TABLE OF SOURCE DATA

DERIVATIVE	TEST NUMBER	RUN NUMBERS
C_{m_α}, C_{N_α}	MSFC 504	16, 17, 18, 19, 20, 53, 54, 58, 63
	MSFC 507	29, 30, 31, 32, 110, 135, 146, 147, 148
	LaRC 8-TPT 604	1, 2, 3, 4, 5
	LaRC UPWT 964	7, 11, 17
	LaRC UPWT 969	9, 10, 16, 48
	LaRC LTPT 75	7
C_{n_β}, C_{ℓ_β}, C_{Y_β} $\alpha = 0°$	MSFC 504	11, 12, 13, 14, 15
	MSFC 507	57, 58, 59, 60, 123, 132, 140, 155, 156, 157
	LaRC UPWT 964	8, 12, 18
	LaRC LTPT 75	7, 17
C_{n_β}, C_{ℓ_β}, C_{Y_β} $\alpha = 10°$	MSFC 507	110, 111, 112, 113, 114, 135, 141, 152, 153, 154
	LaRC UPWT 964	9, 13, 19
	LaRC LTPT 75	7, 17
$C_{n_{\delta_r}}$ $C_{\ell_{\delta_r}}$, $C_{Y_{\delta_r}}$ $\alpha = 0, 10, 20$	MSFC 507	5 & 126, 6 & 127, 7 & 128, 8 & 129
	LaRC UPWT 969	54 & 56, 22 & 26, 24 & 27
$C_{n_{\delta_a}}$, $C_{\ell_{\delta_a}}$ $C_{Y_{\delta_a}}$, $\alpha = 0, 10, 20$	MSFC 507	12 & 16, 11 & 15, 10 & 14, 9 & 13
	LaRC UPWT 969	58 & 59, 3 & 29, 5 & 30
$C_{L_{\delta_e}}$, $C_{m_{\delta_e}}$ $\alpha = 0, 10, 20$	MSFC 507	4 & 5, 3 & 6, 2/1 & 7, 1/1 & 8, 146 & 151, 147 & 150, 148 & 149
	LaRC UPWT 964	27 & 31, 25 & 30, 23 & 29
	LaRC UPWT 969	48 & 54, 10 & 22, 16 & 24
	LaRC 8-TPT 604	5 & 20, 4 & 19, 3 & 18, 2 & 17, 1 & 16